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IMPROVING DEPARTMENT OF DEFENSE GLOBAL DISTRIBUTION PERFORMANCE THROUGH NETWORK ANALYSIS

by

Justin A. Thompson

June 2016

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In October 2015, the United States Transportation Command (USTRANSCOM) implemented a new global shipping performance assessment method. USTRANSCOM assesses shipping lane performance by analyzing the distribution of the start-to-finish shipping time for all requisitions during a given time period and comparing the 85th quantile to an established time standard for the lane. The command assesses overall network performance using the total number of shipping lanes that perform better than the standard. Previously, USTRANSCOM grouped shipping lanes according to shipping method and destination with no consideration given the origin. The new method includes the origin information. Using parametric and non-parametric statistical tests and data analysis techniques, we show that the addition of requisition origin information enables more accurate analysis of the shipping network. Optimization provides node improvement recommendations. We find that focusing improvement on commercial air and military air shipments provide the greatest overall network performance increase.

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IMPROVING DEPARTMENT OF DEFENSE GLOBAL DISTRIBUTION PERFORMANCE THROUGH NETWORK ANALYSIS

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ABSTRACT

In October 2015, the United States Transportation Command (USTRANSCOM) implemented a new global shipping performance assessment method. USTRANSCOM assesses shipping lane performance by analyzing the distribution of the start-to-finish shipping time for all requisitions during a given time period and comparing the 85th quantile to an established time standard for the lane. The command assesses overall network performance using the total number of shipping lanes that perform better than the standard. Previously, USTRANSCOM grouped shipping lanes according to shipping method and destination with no consideration given the origin. The new method includes the origin information. Using parametric and non-parametric statistical tests and data analysis techniques, we show that the addition of requisition origin information enables more accurate analysis of the shipping network. Optimization provides node improvement recommendations. We find that focusing improvement on commercial air and military air shipments provide the greatest overall network performance increase.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Analytic Hierarchy Process
CONUS	Continental United States
DDSP	Defense Distribution Susquehanna, Pennsylvania
DLA	Defense Logistics Agency
DOD	Department of Defense
GSA	General Services Administration
IDL	Integrated Distribution Lane
IPG	Issue Priority Group
JDDE	Joint Deployment and Distribution Enterprise
LRT	Logistics Response Time
MILAIR	Military Air, pallets built by aerial port
OCONUS	Outside of the Continental United States
PACOM	Pacific Command
RSS	Residual Sum of Squares
SDDB	Surface Distribution Database
TDD	Time Definite Delivery
UPS	United Parcel Service
USTRANSCOM	United States Transportation Command

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EXECUTIVE SUMMARY

The Department of Defense continuously seeks to improve the performance of the logistical support network. It defines Logistic Response Time (LRT) as total number of days to fill a supply requisition. This is the primary analysis metric used by the United States Transportation Command (USTRANSCOM) to assess the network's performance. The LRT is defined as the sum of the days a requisition remains in each of four segments of the network: Source, Supplier, Transporter, and Theater, with each segment containing various sub-elements. When assessing network performance, USTRANSCOM analyzes the distribution of LRTs grouped by Transporter and Theater segment information, called "lanes," against a delivery time standard. USTRANSCOM recommends improvements to poor performing lanes, thus improving the overall network. The current method of grouping LRTs into lanes does not include information regarding the organization which supplies a requisition and does not account for the entirety of the time a requisition spends in the system. This lack of information makes it difficult to identify areas for improvement. USTRANSCOM seeks to redefine the grouping method to include the supplier information, potentially providing greater analytic fidelity but increasing the number of lanes requiring analysis by an order of magnitude. This research analyzes network performance under the new grouping method, replacing lanes with "streams," to determine effective network improvement recommendations which focus on the segments within the network, thus improving multiple interconnected streams, as opposed to focusing on improving complete lanes.

USTRANSCOM J4, Metrics Branch provided the data used for this research from the Strategic Distribution Database (SDDB), the system of record for all Department of Defense requisition data. The data consists of all completed requisitions from all services from February 2015 to January 2016. As one of the most significant findings of our analysis, we show significant problems with the

quality of the data within the SDDB. Effective improvement recommendations require adequate data on requisition time in the system. However, nearly 50% of the Transporter and Theater time information is missing.

The analysis focuses on the total time requisitions spent in each of the four segments of the requisition network. We first demonstrate that the four segments are independent. Segment independence allows improvements to a single segment to improve the overall stream's performance linearly. Using this result, we shift the focus of improvement recommendations from the set of over 2500 streams to the 84 stream elements.

Processes within the Source segment assign priorities, 1 to 3, to requisitions. We examine the hypothesis that priority has no effect on the median time a requisition spends in the Supplier, Transporter, or Theater segments. Using hypothesis testing we determine that the priority assigned to a requisition affects the median Supplier and Theater segment time, but not the Transporter segment. We also find statistical evidence supporting the hypothesis that requisitions shipped via ocean have different shipping times. However, additional analysis shows that priority 3 shipments, those with the lowest priority, moving via ocean have less overall time in the system than priority 1 shipments, those with the highest priority, moving via ocean.

Leveraging the segment independence finding, we then determine the segments that have the greatest potential to improve the most streams. First, we calculate the total number of streams which perform to standard associated with a given segment element. Second, we improve the performance of the segment element by decreasing the time each requisition spent in that segment element by one day. Third, we recalculate the number of associated streams performing to standard. We examine the improvement associated with each element in the network using this algorithm. Linear optimization finds the maximum number of streams meeting the standard given a set number of total days the network can be improved. Using this algorithm, we find that, given 20 improvement days, we can improve the total number of streams that meet the standard within the continental United States by between 40 and 59 streams. With the same budget of 20 improvement days we can improve the total number of streams that meet the standard outside the continental United States by between 149 and 187 streams.

We recommend the Department of Defense make a significant effort to improve data quality. The large number of missing values makes network assessment and process visibility difficult. We also recommend USTRANSCOM redefine the LRT grouping method to include the Supplier, Transporter, and Theater segments and focus improvement recommendations of the elements within the segments, not entire lanes.

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I. INTRODUCTION

A. BACKGROUND

1. United States Transportation Command

"United States Transportation Command (USTRANSCOM) provides full-spectrum global mobility solutions and related enabling capabilities for supported customers' requirements in peace and war," according to USTRANSCOM's website. Department of Defense (DOD) Directive 5158.04 (2007) assigns USTRANSCOM as the DOD Distribution Process Owner, officially tasked to "provide effective and efficient air, land, and sea transportation for the Department of Defense, in times of peace and war" (p. 4). USTRANSCOM Metrics and Analysis Branch defines, develops, tracks, and maintains outcomes-based supply chain metrics to measure the performance of the Joint Deployment and Distribution Enterprise (JDDE) (personal conversation, LTC John Hiltz, February 9, 2016.)

2. Requisition Processing

All branches of the service use a common requisition system, enabling USTRANSCOM to provide timely, equal-quality service to all components. While all services maintain their own logistics management systems, all services submit requisitions through the same DOD-managed system. A centralized system allows uniform support to all services. Defense Logistics Manual 4000.25-1, *Military Standard Requisitioning and Issue Procedures*, governs DOD requisition fulfillment under the supervision of the Office of the Assistant Secretary of Defense for Logistics and Materiel Readiness. The requisition fulfillment process consists of two parts: Source Segment and Delivery. The Delivery portion has three segments: Supplier, Transporter, and Theater. Figure 1, USTRANSCOM Requisition Fulfillment, depicts the process for an example requisition. First, a unit submits a request to its Supply Support Activity (top right of Figure 1). The Supply Support Activity processes the request and submits a requisition into the

DOD system. The map shows only information flowing through the Source Segment, then materiel flowing through the Supplier, Transporter, and Theater Segments. The process ends when the requisitioning Supply Support Activity reports receipt of the requisition into the DOD system. The depicted metrics measure the total days a requisition remains in the associated portion of the system. USTRANSCOM measures all metrics in days. The level 1 metric, Logistic Response Time (LRT), measures the total time a requisition remains in the system, not including backorder time. The Level 2 metrics, Source Cycle Time and Delivery Cycle Time, measure the information processing time and materiel shipping times respectively. The Level 3 metrics measure the total time a requisition remains in a given segment.

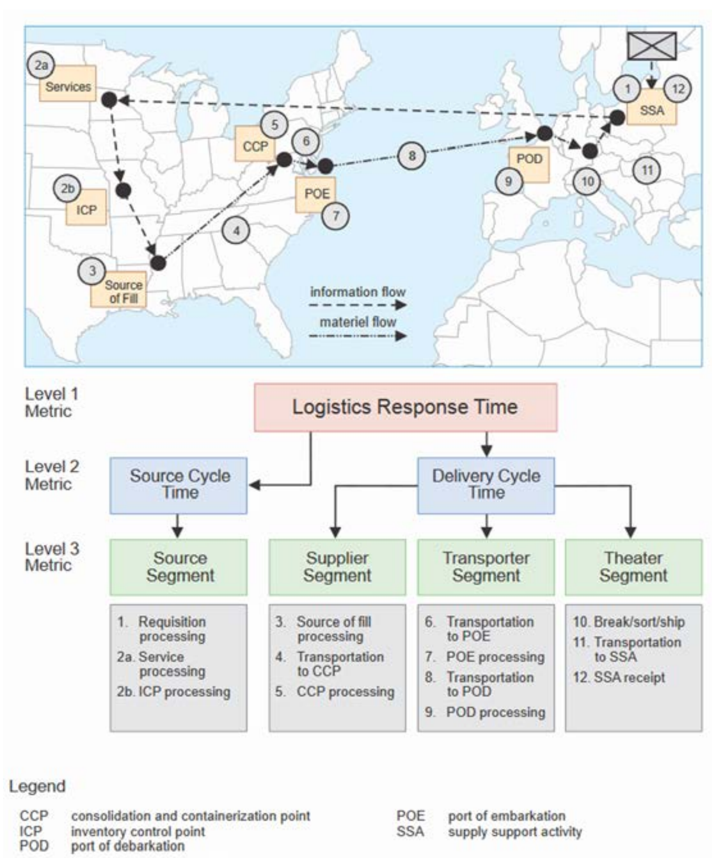


Figure 1. USTRANSCOM Requisition Fulfillment Flow. Adapted from Joint Chiefs of Staff (2013a).

Requisition processing occurs in the Source Segment. Actions include:

- Initial requisition from a unit Supply Support Activity.
- Verifying requisition validity.
- Assigning an Issue Priority Group (IPG), required delivery date, and IDL to the requisition.
- Directing a requisition to a specific supplier and transporter for fulfillment through a Materiel Release Order.
- Coordinating with the supplier to ensure the requisition is correctly filled.
- Redirecting requisitions and redrafting Materiel Release Orders as necessary.

Once a supplier accepts the Materiel Release Order the requisition enters the Supplier Segment. Responsibilities of the assigned supplier include locating the item within its inventory and coordinating with the assigned transporter for pick-up. The specific tasks a supplier must complete depend on the transportation mode assigned to a requisition. In general, Supplier Segment organizations are responsible for:

- Locating requisitioned items within their network.
- Preparing and packaging the requisition for shipment.
- Transporting the package to the transporter pick-up location.

The requisition enters the Transporter Segment upon acceptance by the transporter. The assigned transporter moves the requisition from the supplier pick-up location to the destination's entry point. The transporters must use the assigned transport method, but USTRANSCOM does not specify routes for standard shipments. The transporters may ship a requisition along any route they wish. The transporter's specific tasks depend on the transportation method assigned to a requisition. In general, the transporter's only responsibility is moving the requisition from the designated pick-up location to the destination entry point. Ocean and military air transporters have additional Port of

Embarkation and Port of Debarkation requirements including palletization, containerization, and operations at the port.

Once the requisition arrives at the destination entry point and the relevant reception agent accepts the requisition, it enters the Theater Segment. The reception agent breaks consolidated orders into individual orders (e.g., emptying containers) and coordinates requisition movement to the requesting unit. Process completion occurs when the requesting Supply Support Activity closes out the requisition in the service-specific system. This supply transaction stops Logistic Response Time (LRT) calculation.

3. Established Shipping Standards

To evaluate the effectiveness of the JDDE, the Department of Defense establishes a set of annually updated delivery time standards called Time Definite Delivery standards (TDD) (DoDM 4140.01-V8, 2014a, p. 8). The Joint Staff defines a TDD standard as the maximum number of days the supply chain can take to deliver requisitioned materiel using a given shipping lane (2013a, p. V-20). These standards result from negotiations between USTRANSCOM Metrics and Analysis Branch (responsible for maintaining the standards (Under Secretary of Defense (AT&L), 2007, p. 5), distribution suppliers, and end customers. The standards apply to Integrated Distribution Lanes (IDL), defined by a combination of the requisition origin, mode of transportation, and destination. The negotiations build three TDD categories based on Issue Priority Group (IPG), the requisitioning unit's operational need, and the Required Delivery Date. The USTRANSCOM assigns the shortest TDD to the highest priority requisitions, IPG 1, and the longest TDD to the lowest priority requisitions, IPG 3. Underway Navy vessels receive additional time beyond the TDD to allow for requisitions to move from the land-based supply activity to the underway vessel. The associated IDL and TDD category determine the number of days added.

4. Current Analytical Method

USTRANSCOM Metrics and Analysis Branch assesses JDDE performance by measuring the performance of each IDL. USTRANSCOM aggregates the requisitions that utilized a particular IDL, then evaluates the overall performance using the 85th percentile of the aggregated LRTs. We define the IDL's performance as acceptable, or "good," if the 85th percentile is less than or equal to the assigned TDD standard. We define the IDL as "poor" if the 85th percentile is greater than the assigned TDD standard. Figure 2 depicts a sample IDL distribution analysis of a "poor" performing IDL.

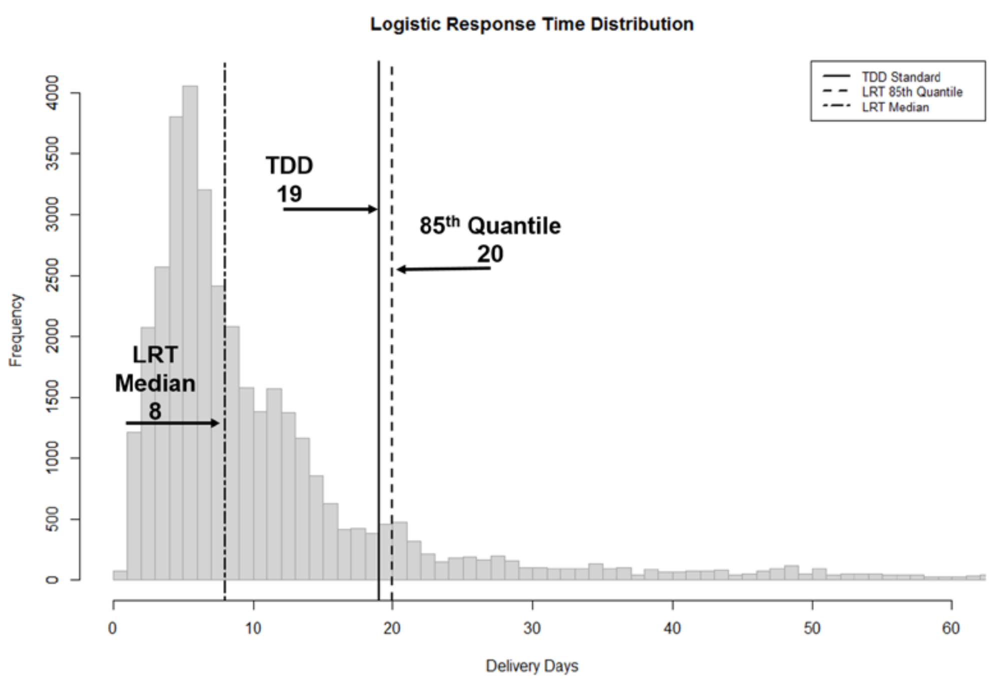
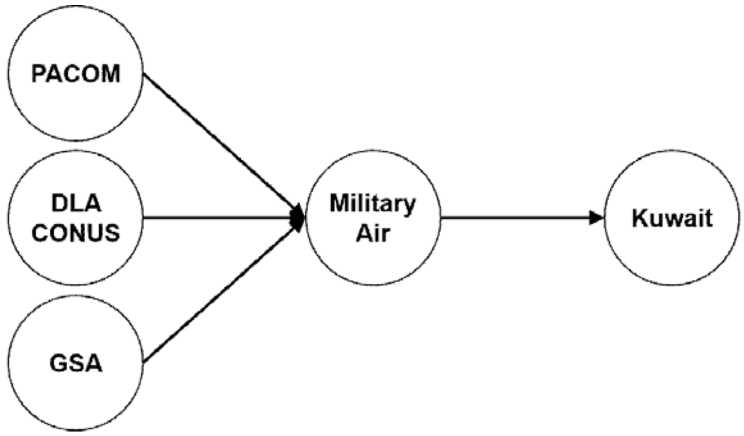


Figure 2. Sample IDL Analysis

Analysis of the IDLs assists the identification of capability gaps in the distribution system. After identifying a "poor" IDL, the Analysis and Metrics Branch provides improvement recommendations to support tasks specified by the Under Secretary of Defense (AT&L) (2007, p. 2–3). Because the methodology focuses on the IDL, JDDE improvement focuses on increasing the efficiency of the Transporter and Theater Segments. The methodology fails to consider the requisition's full course through the network as it ignores the Supplier Segment. Basing the analysis on the IDL ignores the Supplier Segment information.

A requisition's LRT represents the sum of the total time spent in the four segments, not including backorder time (see Figure 1). However, the IDL combines only a subset of the segments: the Transporter Segment and the Theater Segment. Not including the additional segments presents an incomplete picture of a requisitions movement through the network. For example, consider three requisitions assigned the same IDL with the same total days in the Transporter and Theater Segments and different Supplier Segment times. The resulting LRTs might be different. Because aggregating at the IDL loses the Supplier information, identifying which process to improve becomes challenging. Figure 3 shows an example of an IDL that performs "poorly," because two of the three requisitions have LRTs that exceed the TDD. Under the current approach, USTRANSCOM would focus improvement efforts on the theater and transporter segments. But even if we were to reduce the Transport Segment time and the Theater Segment time to zero the IDL would remain "poor" due to poor performance in the Supplier Segment.



Total Time Distribution	
Requisition 1	40.0
Requisition 2	35.0
Requisition 3	20.0
Group Standard	22.0
Metric	

Supplier Segment Time	
Requisition 1	33.0
Requisition 2	28.0
Requisition 3	13.0

Transporter Segment Time	
Requisition 1	2.0
Requisition 2	2.0
Requisition 3	2.0

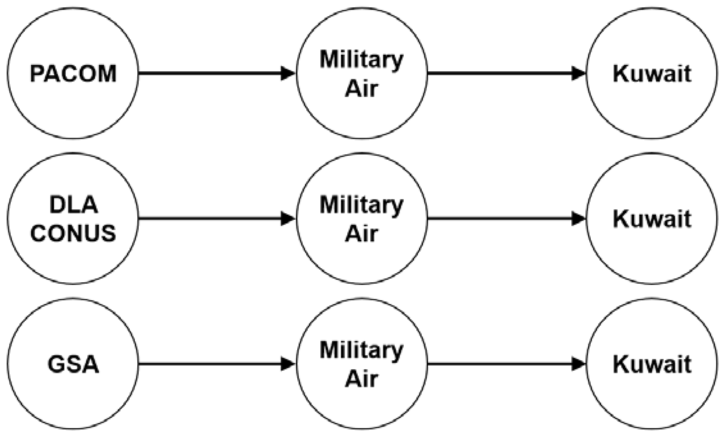
Theater Segment Time	
Requisition 1	5.0
Requisition 2	5.0
Requisition 3	5.0

Current grouping masks supplier time; confounds analysis.

Figure 3. IDL Improvement Example. Reducing the transporter and theater segment times to zero would result in an 85^{th} quantile of 31.5, greater than the TDD standard. No amount of IDL improvement would redefine it.

Underway Navy vessels similarly complicate the analysis. Items requisitioned by vessels at sea have to be moved from the receiving port, the start of the Theater segment, to sea via a Navy supply vessel. Because of this, an IDL can have two TDD standards at the requisition level: one for vessels in a particular port and one for underway vessels receiving sea-based resupply from the same port. However, aggregating the requisitions masks the difference.

In November 2015 USTRANSCOM and the Joint Staff implemented a new analysis strategy replacing the IDL with a distribution “stream.” USTRANSCOM defines a distribution stream as a combination of the Supplier, Transporter, and Theater Segment information plus an afloat additive as necessary. Figure 4 depicts the same requisitions as Figure 3 under the new stream definition. USTRANSCOM currently assigns TDD standards based on the Transporter and Theater Segments, resulting in the same standard for the three streams. Using this definition the difference in source times becomes clear, driving improvement emphasis to the correct place.



Stream 1 Summary	
LRT	40.0
IDL TDD	22.0
85th quantile	40.0
Stream 2 Summary	
LRT	35.0
IDL TDD	22.0
85th quantile	35.0
Stream 3 Summary	
LRT	20.0
IDL TDD	22.0
85th quantile	40.0

Supplier Segment	
Requisition 1	33.0
Requisition 2	28.0
Requisition 3	13.0

Transporter Segment	
Requisition 1	2.0
Requisition 2	2.0
Requisition 3	2.0

Theater Segment	
Requisition 1	5.0
Requisition 2	5.0
Requisition 3	5.0

Figure 4. Stream Improvement Example. Analyzing the three different streams makes clear which elements within the Supplier Segment require improvement to redefine the streams as “good” performing. In this example all three streams are “poor” performing.

Figure 5 shows streams encompassing more of the total requisition process. Adding more information allows a more complete analysis picture, but increases the scope of the analysis from just over 200 IDLs in given analysis period to in excess of 2,500 distribution streams. The number of streams requires USTRANSCOM to shift from focusing on shipping lane improvement to focusing on improving individual stream elements creating challenges in identifying opportunities for process improvement.

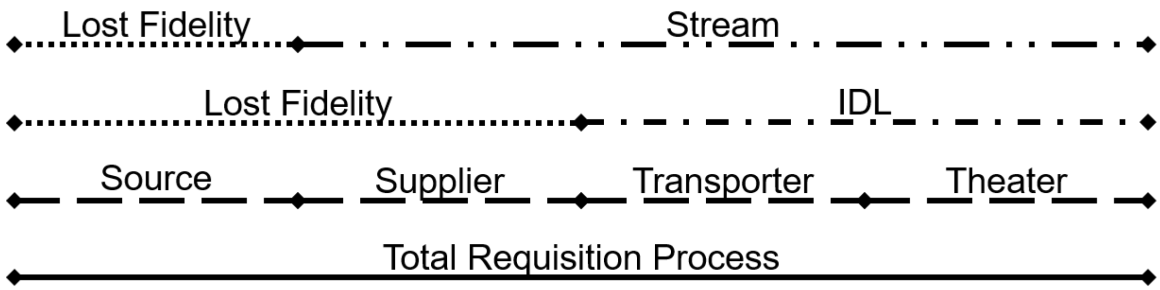


Figure 5. Segment Chart

5. Strategic Distribution Database (SDDB)

The Department of Defense tasks all components to "develop and execute a supply chain data management strategy that promotes the use of shared enterprise services" (2014b, p. 2). To accomplish this, RAND developed the Strategic Distribution Database, an integrated database that compiles distribution performance data from a number of sources into a single system (Mahan, Moon, 2007, p. 12). The SDDB provides a common data structure for analysis by all DOD components and enables JDDE assessment. The Defense Logistics Agency (DLA), Office of Research and Resource Analysis, maintains the SDDB. Other DOD elements, including USTRANSCOM, routinely access SDDB data and add additional unit-specific requisition data to conduct analysis.

The SDDB focuses on requisitions in support of the warfighter. DLA excludes certain types of USTRANSCOM-managed shipping data not considered to be in support of the warfighter supply requisitions. These include contingency operation movement of troops and equipment into, out of, and around theater; the retrograde of unneeded, but not unit-owned, equipment from a contingency theater to supply depots; and movement of Defense Commissary Agency foodstuffs. SDDB customers use approximately 75% of the available SDDB data for analysis (Mahan, 2007 p. 14). DLA excludes the remaining 25% through business rules related to the data quality of the databases compiled into the SDDB. Many of the excluded transactions move through the same network as the captured transactions and utilize network capacity. The SDDB contains data only for operations across a subset of the JDDE. Therefore, process improvement recommendations based on analysis of SDDB data may not apply to the entire network.

B. PURPOSE

This research analyzes the past performance of distribution streams across the JDDE to determine network improvement recommendations. This leads to the following research questions:

- Is there statistical evidence that Issue Priority Groups are treated differently within the stream segments?
- Which stream segment has the greatest impact on stream performance?
- Which segment element gives the greatest overall network improvement for the lowest improvement day cost?

The analysis utilizes one calendar year of completed USTRANSCOM requisitions from the SDDB.

C. SCOPE

We limit the analysis to completed requisitions. We exclude any requisition not fulfilled by the data extraction time or was partially fulfilled and subsequently canceled. We use the stream information only as a means to focus the performance analysis. The scope of this research does not include identifying issues at individual locations. The research does not consider contracted carriers' performance, only the overall performance of a transport method. Finally, at the request of USTRANSCOM, we do not apply weighting to streams based on the requisition volume or exclude any stream from the analysis.

This research is not intended to identify single points of error within the system (e.g., "the Defense Distribution Depot in Anniston, AL, had increased requisition processing time this month") but to analyze the stakeholder organizations responsible for elements within the JDDE. USTRANSCOM Metrics and Analysis Branch will use the conclusions from the research to make stream improvement recommendations.

We assume all data used for this research is accurate and as complete as possible. Not all transactions at a stream element meet the criteria for inclusion in the SDDB. Additionally, pre-processing for data quality excludes 25% of available requisition data. Thus, we know the data is incomplete. However, the SDDB is the requisition data system of record. As such, USTRANSCOM and the supported Combatant Commands use the SDDB data for logistical support analysis.

Finally, we assume that all requisition processing and shipping occurs according to Defense Logistics Manual 4000.25 (2015), Defense Logistics Management Standards, and Defense Transportation Regulation 4500.9-R, Cargo Movement. Under these assumptions the characteristics of an individual requisition have no effect on the shipping time.

D. RELATED WORK

1. Evaluating Intermodal Transportation in Thailand

Kunadhamraks and Hanaoka (2008) investigate applying fuzzy set theory to the Analytical Hierarchy Process (AHP) to measure logistical performance of intermodal freight transportation. In the case study, Kunadhamraks and Hanaoka define intermodal freight transportation as “the movement of goods in one and the same loading unit or vehicle by successive modes of transport without handling of the goods themselves when changing modes” (p. 324). For example multiple packages consolidated in a shipping container, the container then being transported to a port by truck or rail and then loaded onto a ship. They argue that past measurements of logistical performance focus too heavily on only hard numbers, measuring only cost or customer service. These measurements fail to take into account all elements that decision makers deem important, such as reliability, or apply a weighting scale to those elements. Kunadhamrak and Hanaoka constructed a multi-criteria metric using a combination of a fuzzy-analytical hierarchy process (fuzzy-AHP) and fuzzy-multi-criteria analysis. They focused the performance metric on the choice of shipping mode, framed as a human decision problem. The application of fuzzy set theory emulates human perceptions within the decision process.

Kunadhamrak and Hanaoka present a three-level fuzzy-AHP hierarchy (Figure 6) which provides a multi-criteria comparison of intermodal shipping lanes using survey data from logistics experts and performance data from the network. However, the resulting comparison metric loses critical information due to AHP and it is not possible to adjust the input parameters and recalculate the result without executing the entire process again. Thus, it is not efficient as a basis for intermodal shipping lane improvement analysis.

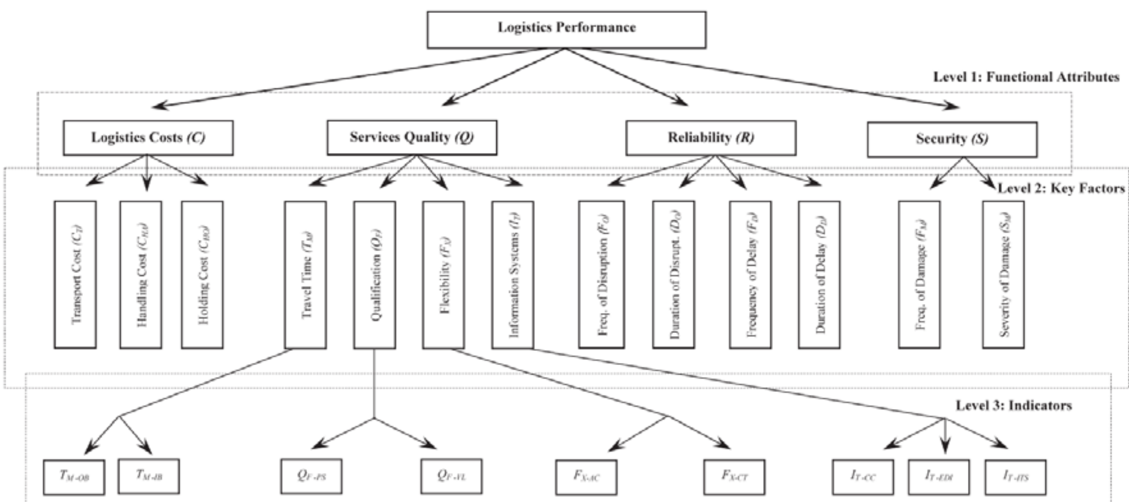


Figure 6. Hierarchy Framework for Evaluating Logistics Performance. Source: (Kunadhamrak and Hanaoka, 331).

2. United Parcel Service Shipping and Analysis Procedures

United Parcel Service (UPS) faces similar analytic challenges to USTRANSCOM when assessing network performance. Similar to the JDDE system, UPS assigns each shipment a total delivery time ceiling. But where the JDDE assigns an IDL, and the associated TDD, to shipments with certain characteristics (IPG and destination), UPS assigns a required delivery date based on the shipping contract for each unique order. UPS uses the required delivery date to assign a shipping route and timeline using a standard transportation problem with many thousands of constraints. To achieve this, UPS maintains a very large database of baseline transit times on all nodes and arcs within the UPS network. UPS also uses barcode tracking at pre-determined key points along routes to scan for late shipments. If a shipment is late, UPS analysts generate a new route based on the shipment's current location (Randy Rupp, personal communication, February 29, 2016).

Because UPS dynamically manages a shipment's route, it does not use a start-to-finish analysis similar to USTRANSCOM's. Instead, it analyzes the performance of the individual nodes and arcs (warehouses and transporters). UPS leverages tracking technology to continuously add to a database of transit times, similar to the SDDB, and analyzes the segment performance against a binding standard for each individual node and arc. Improvements to the individual portions of the network accomplish the goal of overall start-to-finish reliability improvement because UPS controls the routing through the network. In its analysis, UPS found that issues during shipping (e.g., extreme weather or problems with railroad carriers) caused the majority of late shipments (Randy Rupp, personal communication, February 29, 2016).

While node-and-arc based analysis is a successful technique for UPS, a similar approach would be difficult to implement for USTRANSCOM. Most importantly, as the distribution manager USTRANSCOM does not directly manage any portion of the JDDE. Other organizations conduct distribution execution. In the role of Distribution Process Manager, it contracts companies like UPS, and similar logistics units within the DOD, to provide logistics services, thus a requisition could have various logistics service providers associated it. Including all possible combinations of logistics providers to form a complete network diagram greatly expands the analytic scope. Using a less granular approach allows USTRANSCOM to emphasize areas of the network needing improvement and holding the process manager of those areas accountable.

E. SCOPE

This thesis consists of four chapters. Chapter II consists of an in-depth description of the data used for the research, as well as the methodologies and techniques applied. Chapter III consists of missing value analysis, verifying stream segment independence, and statistical analysis of IPG treatment. It also includes an analysis of improvements and an assessment of the operational needs metric. Finally, Chapter IV provides a summary of the conclusions and recommendations for further study.

II. DATA AND METHODOLOGY

A. DATA

USTRANSCOM J4, Metrics Branch provided the data used for this research from the SDDB. The data consists of one full calendar year (February 2015 to January 2016) of equipment requisitions completed by USTRANSCOM. Each observation represents an individual requisition (defined as a single item type and an integer quantity). USTRANSCOM J4, Metrics Branch and other Combatant Commands regularly conduct analysis using the same data.

We split the data into two sets based on destination: outside the continental United States (OCONUS) and within the continental United States (CONUS). Each observation consists of 227 variables providing specific information:

- The dates on which each step of the requisition process began and ended.
- The number of days spent in each segment.
- The requesting unit and its geographical location.
- The requisition’s assigned depot.
- The shipping method.
- The destination Combatant Command.
- Details of the requisitioned item.
- The shipping priority
- The assigned TDD.

Because different requisitions have slightly different processes, the SDDB does not record every variable for each requisition, resulting in a large number of missing values.

Data input error also causes missing values. Some requisitions have no information on progress through the system, which, for various reasons, causes missing values in the number of days within each process. For example, items transported by commercial ocean vessel rely on the shipping company to populate the information in the database of record. “Direct-from-vendor” shipments also have a large number of missing values as the DOD is not responsible for any portion of the shipping for these shipments. The SDDB only records the requisition’s LRT.

The original OCONUS dataset contains 1,585,691 observations and the original CONUS dataset contains 7,277,722 observations. Although every observation contains missing values, we retain all observations. We use specific analytical methods to carefully handle missing values within the algorithms. We describe these methods in Chapter III. We also eliminate highly correlated variables. Many of the variables of interest are the result of operations on other variables so we exclude the input variables, (e.g., segment start and end dates) as the result contains the required information in all cases. We also exclude variables that provide no useful information, such as the container serial number that the item was shipped in or the unique order reference number.

The resulting dataset contains the stream information, the requisition’s IPG, the number of days in each segment, the requisition’s total shipping time, the TDD standards assigned with the requisition, the requesting unit’s information, and the requisition’s supply class; 31 total variables.

B. VARIABLES

We categorize the variables into four types: Segment Days, Standards, Stream, and Requisition.

1. Segment Days

There are five “Segment Days” variables; each describes the total number of days a requisition remained in a particular segment of the requisition pipeline or the total requisition time (LRT) (see Figure 1). The requisition’s LRT is the sum of the four segment values.

2. Standards

There are five "TDD Standards" variables; each describes the standard number of days for the associated "Segment Days" variables. Every requisition that utilizes a particular stream uses the same set of TDD Standards. The set is additive; the sum of the Source, Supplier, Transporter, and Theater standards, and afloat additive when applicable, equals the LRT TDD Standard.

3. Stream Information

There are five "Stream Information" variables; each describes the stream a requisition moved across in the distribution pipeline. Three variables identify the Supplier, Transporter, and Theater segments of a stream; one variable identifies an afloat additive; and one variable is the overall stream name. The overall stream name is a concatenation of the other four stream variables. The CONUS and OCONUS datasets contain the same Supplier, Transporter, and additive variables. In the OCONUS dataset the Theater variable describes the destination country whereas it describes a geographical region of the United States (Central, West, Southeast, Northeast, and U.S. Other) in the CONUS dataset.

4. Requisition Information

There are four "Requisition Information" variables; two of which describe the requisition's assigned priority group and class of supply in accordance with Joint Publication 4-0, Joint Logistics (2013b, Figure II-2). The other two describe the geographical start and end point for each requisition's materiel movement.

C. METHODOLOGY

1. Segment Independence

Establishing independence of the time a requisition spends in each segment allows analysis of the individual stream segments separately from the full stream. Based on USTRANSCOM's segment definition and LRT calculation method, we hypothesize that the stream segments are independent and the LRT is the additive result. To test the hypothesis we calculate the correlation between the four “Segment Days” variables. We reject the null hypothesis if the correlation between the variables is below 0.10. The hypotheses are:

H_0: “The stream segments are not independent.”

H_a: “The stream segments are independent.”

2. Statistical Analysis of IPGs by Segment

The priority of a requisition indicates urgency. It follows that requisitions of higher priority should move through the system at a faster rate than those of lower priority. We use two hypothesis tests to verify the assumption.

a. Friedman Test

The Friedman Test extends the basic sign test to several related samples. Analogous to parametric two-way Analysis of Variance involving blocks and treatments, the Friedman Test requires the following assumptions (Sprent and Smeeton, 2007, 208):

- The blocks are independent.
- The tested variable is continuous.
- The blocks and treatments have no interaction.
- The data is orderable within the blocks.

Given these assumptions, the Friedman Test’s null hypothesis is that the median of the treatments within a block is the same, thus the ordering of the treatments within each block is random. The alternative hypothesis is that not all the medians are the same. This research uses the Friedman Test on a randomized block design of 3 IPG treatments on *k* segment node blocks.

The treatments are the assigned Issue Priority Group (IPG) and the blocks are the elements within each segment. Each observation, $X_{k,t}$, denotes the median time, in days, for a requisition of treatment *t* to move through segment category *k*. The individual blocks are ranked, with 1 assigned to the smallest, to eliminate the differences between blocks. $R_{k,j}$ denotes the rank of an observation from block *k* of treatment *j*. S_r denotes the sum of squared ranks across all blocks in all treatments. We use S_t for convenience in the notation. We assume the presence of ties in the ranks, so we apply a correction factor, *C*. Sprent and Smeeton (2007) define the Friedman Test statistic as:

$$T = \frac{k(t-1)(S_t - C)}{S_r - C}$$

$$\text{with: } S_i = \sum_{j=1}^{k} R_j$$

$$S_r = \sum_{i=1}^{t}\sum_{j=1}^{k} R_{i,j}^2$$

$$S_t = \sum_{i=1}^{t} \frac{(S_i)^2}{k}$$

$$C = \frac{kt(t+1)^2}{4}$$

For large samples the resulting test statistic has a X^2 distribution with $(t-1)$ degrees of freedom (Sprent and Smeeton, 2007, p. 209). We use hypothesis testing to determine if there is a difference in the median of at least two of the treatments. We reject the null hypothesis at a significance level of 0.01 ($\alpha = 0.05$). The null and alternative hypotheses are:

H_0: "The median days in a segment are equal for all IPGs."

H_a: "The median days in a segment is different for at least one IPG."

b. Nested model F-Test

Consider two linear models, *A* and *B*, where *B*'s independent variables are a subset of *A*'s. If both models perform generally the same we infer that the additional independent variables in *A* are not necessary. We use the residual sum of squares (RSS) of the two models for comparison. Denoting the dimension of model *A* as *p*, the dimension of model *B* as *q*, and the total sample size as *n*; we determine the test statistic as:

$$F = \frac{(RSS_B - RSS_A)/(p-q)}{RSS_A/(n-p)}$$

Then, according to Faraway (2015, p. 34), under the null hypothesis the test statistic *F* has an F-distribution with *(p−q)* numerator degrees of freedom and *(n−p)* denominator degrees of freedom. We reject the null hypothesis if $F > F_{(p-q),(n-p)}$. The models are:

Full model: $$LRT_i = \beta_0 + \beta_{SOURCE_i} D_{SOURCE_i} + \beta_{SUPPLIER_i} D_{SUPPLIER_i} + \beta_{TRANSPORTER_i} D_{TRANSPORTER_i} + \beta_{THEATER_i} D_{THEATER_i} + \beta_{IPG2_i} X_{IPG2_i} + \beta_{IPG3_i} X_{IPG3_{iI}}$$

Small model: $$LRT_i = \beta_0 + \beta_{SOURCE_i} D_{SOURCE_i} + \beta_{SUPPLIER_i} D_{SUPPLIER_i} + \beta_{TRANSPORTER_i} D_{TRANSPORTER_i} + \beta_{THEATER_i} D_{THEATER_i}$$

We use a nested model F-Test to determine which elements within a stream segment treat all IPGs the same. The full model includes the Days in Segment, *D,* variables and the IPG variables, *X*, while the smaller model excludes the IPG variables. We conduct a test on each categorical variable, *i,* associated to a segment that fails to reject the null hypothesis of the Friedman Test. We reject the null hypothesis at a significance level of 0.01 ($\alpha = 0.01$) and conclude that including the IPG information in the model does improve performance. The hypotheses are:

H_0: “including IPG in the model does not improve performance.”

H_a: “including IPG in the model improves performance.”

3. Network Improvement Resource Optimization

Measuring the required stream improvement occurs after establishing stream segment independence. We define improvement as the decrease in total days a requisition remains in a particular pipeline segment. USTRANSCOM compares the 85th percentile of the stream's LRT distribution to the TDD standard to measure performance. The distribution shift required to make the 85th percentile of a "poor" stream less than or equal to the TDD standard defines the required stream improvement. Focusing on the independent elements, values within the segment variables, within stream segments provides the most efficient method of improvement. Improving a single element within a segment may improve multiple streams.

Figure 7 depicts the improvement algorithm. First, we define a maximum number of feasible improvement days for the elements within the network. Establishing the maximum limits unnecessary computation and prevents making unattainable recommendations (e.g., improving a single element by a number of days greater than the maximum time in the elements distribution). The algorithm calculates the total number of "good" streams associated with each element using the method described in Chapter I, section 4. Then, the algorithm loops through all elements, selects all requisitions associated with a segment element, and finds all requisitions that have a "Segment Days" value greater than zero. The algorithm subtracts one day from the LRT and "Segment Days" variable of those requisitions, thereby improving element performance, and recalculates the total number of associated "good" streams. The loop continues until the days improved exceeds the predefined limit.

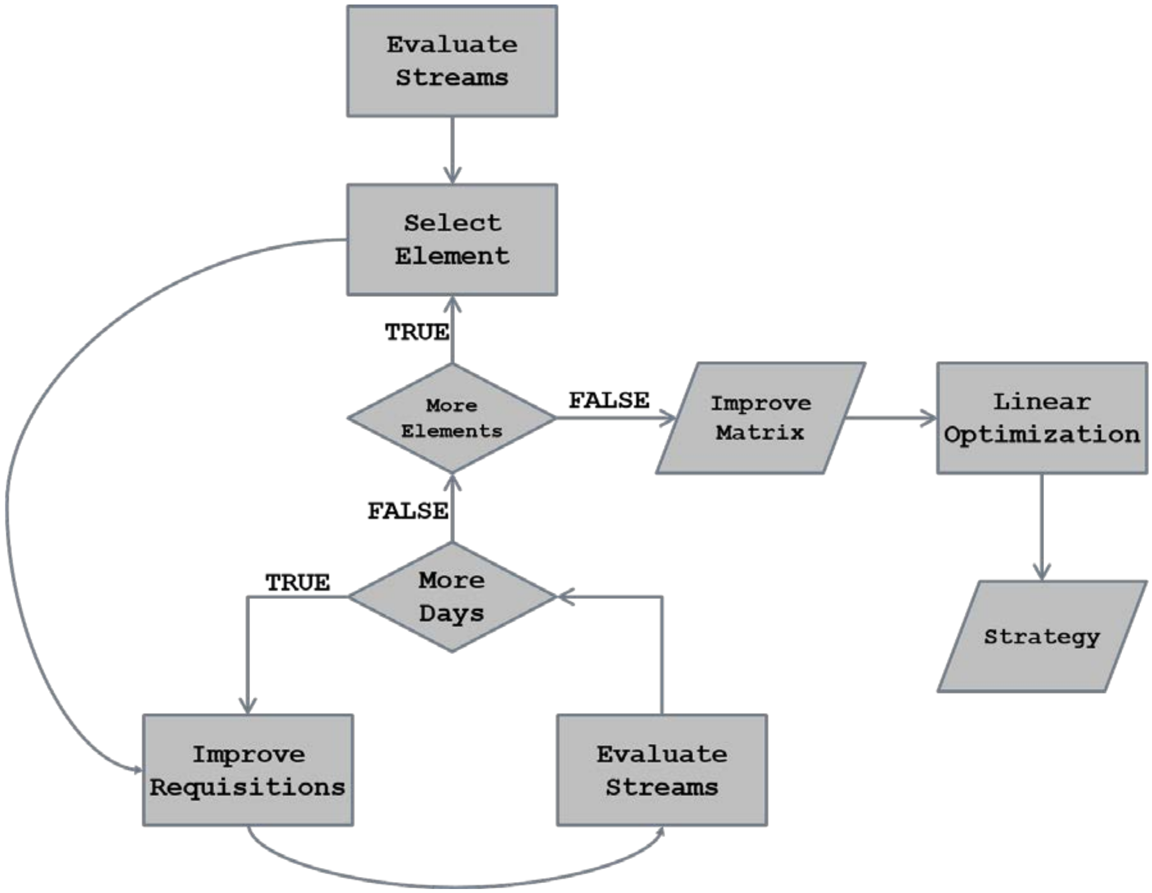


Figure 7. Global Distribution Network Improvement Algorithm

Precautions ensured the results of the analysis functions were feasible. Improvement of a requisition's "Segment Days" variable stops once the value reaches zero, preventing erroneous negative segment times. Also, we did not improve requisitions with missing values in the segment time to stay in line with the previous precaution. The algorithm results in an improvement matrix with stream elements, E_i along the rows and total number of improvement days, *j*, applied to an element along the columns. $S_{i,j}$ represents the total number of "good" streams associated with element *i* after improving the element a total of *j* days (see Table 1).

Table 1. Improvement Matrix

	1	2	3	…	j
E_1	$S_{1,1}$	$S_{1,2}$	$S_{1,3}$	…	$S_{1,j}$
E_2	$S_{2,1}$	$S_{2,2}$	$S_{2,3}$	…	$S_{2,j}$
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
E_i	$S_{i,1}$	$S_{i,2}$	$S_{i,3}$	…	$S_{i,j}$

We use linear programing to find the improvement strategy that maximizes the total number of "good" streams. We constrain the optimization to ensure the algorithm selects an element no more than once and we impose an additional constraint based on the improvement days budget. The model formulation follows:

Indices

i	stream element
j	days

Sets

I	set of stream elements $I=\{1,2,\ldots,I\}$
J	set of improvement days $J=\{1,2,\ldots J\}$

Parameters

$S_{i,j}$	total "good" streams for element *i* after being improved *j* days
budget	total number of days available for improvement

Variable

$X_{i,j}$	binary variable taking value 1 if element *i* is improved *j* days, 0 otherwise

$$\max \sum_i \sum_j X_{i,j} S_{i,j}$$

$$s.t.$$

$$\sum_j X_{i,j} \le 1 \qquad \forall i \in I$$

$$\sum_i \sum_j j X_{i,j} \le budget$$

$$X_{i,j} \in \{0,1\} \qquad \forall i \in I, \forall j \in J$$

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III. ANALYSIS

An initial review of the data shows potential data quality issues. While we find no missing values in the Stream Information variables, the associated "Segment Days" variables contain a large number of missing values. Additional analysis shows high variances in the "Segment Days" for all elements and the LRT distributions for all complete streams, indicating additional data quality issues. We proceed by first examining the missing values to ensure that enough information remains in the data to present feasible and usable results. We then verify segment independence, evaluate the treatment of requisitions in different segments using hypothesis testing, and finally find the best improvement strategies.

A. DATA QUALITY

We find many observations in the SDDB with missing values in the "Segment Days" variables. Table 2 provides the proportion of missing values by stream segment for each data set. Approximately 50% of observations in both data sets are missing one or more values in the "Segment Days" variables. Figure 8 depicts a breakdown of the missing values by element for the CONUS network.

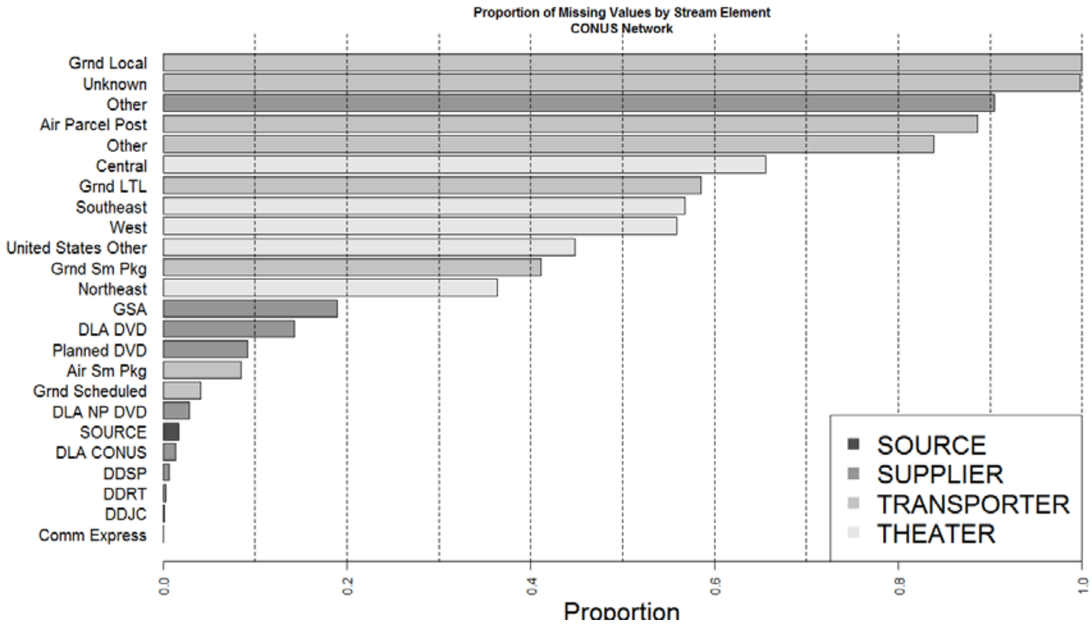

Figure 8. Missing Values. Proportion of values missing from the "Segment Days" variable for the associated element for the CONUS network. Proportion missing is based on the total number of requisitions associated to the element.

Table 2. Proportion of Missing Values in the Associated "Segment Days" Variable

Segment	CONUS	OCONUS
Source	0.0168	0.0816
Supplier	0.196	0.0892
Transporter	0.553	0.127
Theater	0.553	0.147

Both data sets also contain erroneous entries. Over 1000 observations report an ocean transit time of zero days. Approximately 90% of the zero-day transit time requisitions originate from CONUS with OCONUS destinations. Also, we discover 20 requisitions with complete variables where the sum of the "Segment Days" variables does not equal the requisition's LRT. We apply the same treatment to the zero-day ocean transit entries as with missing values as described in Chapter II, Section C, Paragraph 3. We exclude the other erroneous values.

B. DATA SET COMPARISON

We focus initially on analysis of the complete data set. We assumed the CONUS and OCONUS networks operated as a single network and that improvements made to CONUS data would affect OCONUS streams. To confirm the assumption we attempted to separate the data and determine commonalities within the stream variable elements.

Defining the stream network segregates the destination elements into CONUS and OCONUS sets. We assume the stream depot and transportation method variables overlap heavily between the two data sets. Further investigation shows overlap between the CONUS and OCONUS depots and almost no overlap between the transportation methods (see Table 3). USTRANSCOM primarily uses contracted ground transportation for CONUS requisition shipments. OCONUS requisition shipments primarily use contracted air or ocean. Only one CONUS requisition utilized the shared element, commercial express. We further segregate the stream network by destination and transportation method to reflect the difference in transportation methods.

Table 3. Shared Elements by Segment Variable. See Appendix E for Acronym List

DEPOT		
CONUS	**OCONUS**	**OVERLAP**
DLA CONUS	DLA CONUS	DLA CONUS
DLA DVD	DLA DVD	DLA DVD
DDSP	DDSP	DDSP
DDJC	DDJC	DDJC
OTHER	OTHER	OTHER
DLA NP DVD	DLA NP DVD	DLA NP DVD
PLANNED DVD	PLANNED DVD	PLANNED DVD
GSA	GSA	GSA
DDRT	EUCOM	
	CENTCOM	
	PACOM	
TRANS METHOD		
CONUS	**OCONUS**	**OVERLAP**
COMM EXPRESS	COMM EXPRESS	COMM EXPRESS
GRND LOCAL	MILAIR	
GRND SM PKG	OCEAN	
AIR SM PKG	MILALOC	
GRND SCHEDULED	CAT A	
UNKNOWN	OTHER TRUCK	
OTHER	LOCAL TRUCK	
AIR PARCEL POST	SCHEDULED TRUCK	
GRD LTL	AIR SM PKG	

The large number of shared elements in the stream depot variables indicates a relationship between the CONUS and OCONUS networks. The Supplier element value represents an agency responsible for a requisition or a requisition source category. Many elements in the Supplier Segment have sub-levels that provide specific depot information. Therefore, a simple comparison of the elements does not provide the depth needed to determine if the networks are deeply connected. After comparing the two network’s Supplier factor sub-levels, we find 33% of the sub-levels do not appear in both data sets. For example, DLA CONUS represents a network of 64 depots located across the United States.

45% of the depots provide no requisitions to OCONUS. Analysis of the "Segment Days" distributions for the common elements shows differences.

Slightly higher LRT variances appear in the OCONUS subset than in the CONUS subset. Histograms and boxplots of the DDSP element appear similar as this element represents a single physical depot that supports both CONUS and OCONUS requisitions. As such, the processes for the two destinations may be similar. However, the remaining elements show distinct differences in the distributions. Figures 9 and 10 depict the distributions for DDSP and DLA CONUS elements, with the boxplots showing logarithms for clarity. The distributions show the network connection assumption was incorrect and we maintain the CONUS/OCONUS segregation for the remainder of the analysis.

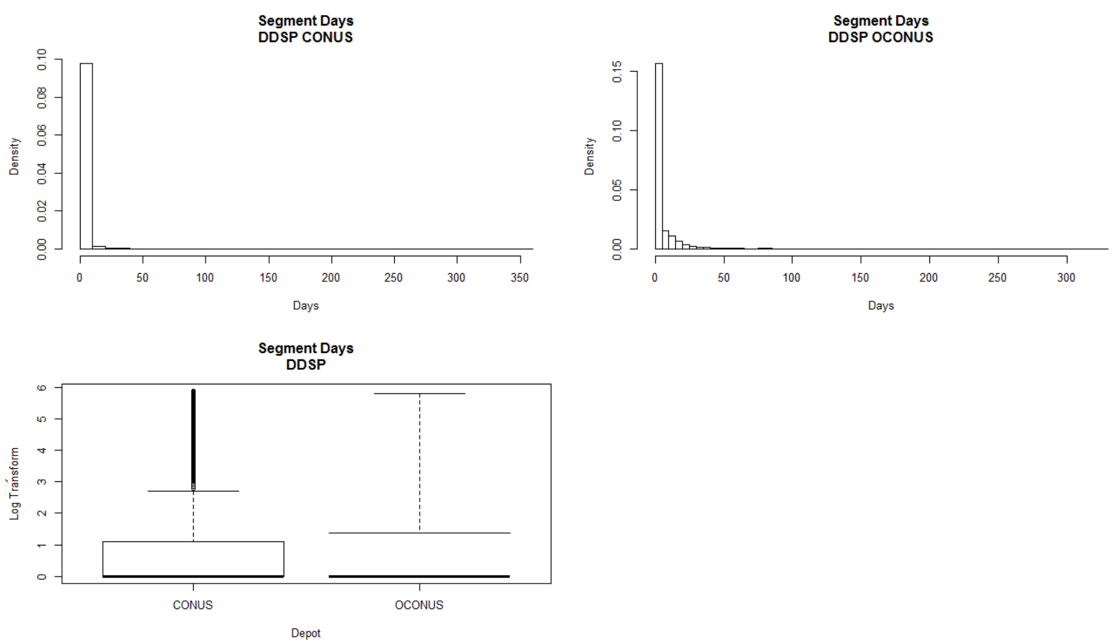

Figure 9. Histograms and Boxplots of the "Segment Days" Distribution: All DDSP Requisitions, Partitioned by CONUS and OCONUS

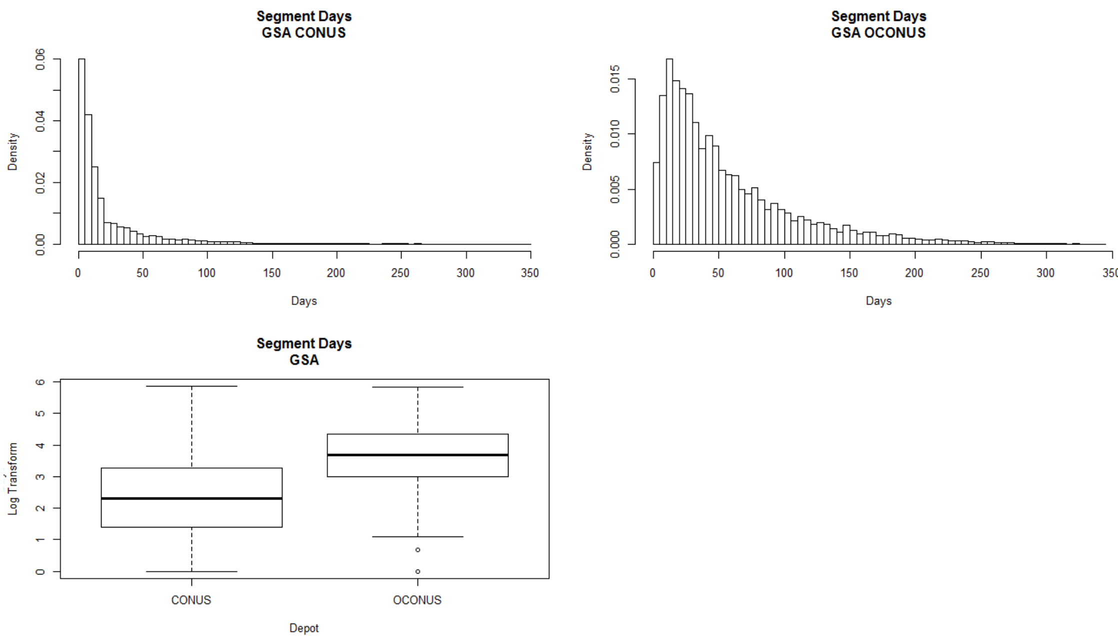

Figure 10. Histograms and Boxplots of the "Segment Days" Distribution: All GSA Requisitions, Partitioned by CONUS and OCONUS

C. SEGMENT INDEPENDENCE

We hypothesize stream segment independence based on how requisitions flow through the network and how USTRANSCOM constructs the streams. The "Segment Days" variables for a particular requisition are sequential, next Segment Day variable begins counting immediately when the previous one ends. The sum of the "Segment Days" variables for a requisition construct the requisition's LRT. If we can establish independence the improvement optimization algorithm can focus on the 84 individual stream elements instead of the 2416 separate streams, reducing the analytic scope, as improving a segment element would then improve all associated streams linearly.

After excluding outliers, the correlation between the "Segment Days" variables is below 0.10 for all variable pairs (Table 4) and no discernable pattern appears in variable scatter plots (Figure 11). We define outliers as any "Segment Days" values greater than 100 days. Excluding these data removes approximately 1.0% of all observations. We use only complete pairwise observations for the analysis. Based on these results we focus improvement analysis on the individual segments.

Table 4. “Segment Days” Correlation Matrix

	SOURCE	SUPPLIER	TRANSPORT	THEATER
SOURCE	1.000	0.092	0.013	0.055
SUPPLIER	0.092	1.000	0.059	0.049
TRANSPORT	0.013	0.059	1.000	0.022
THEATER	0.055	0.049	0.022	1.000

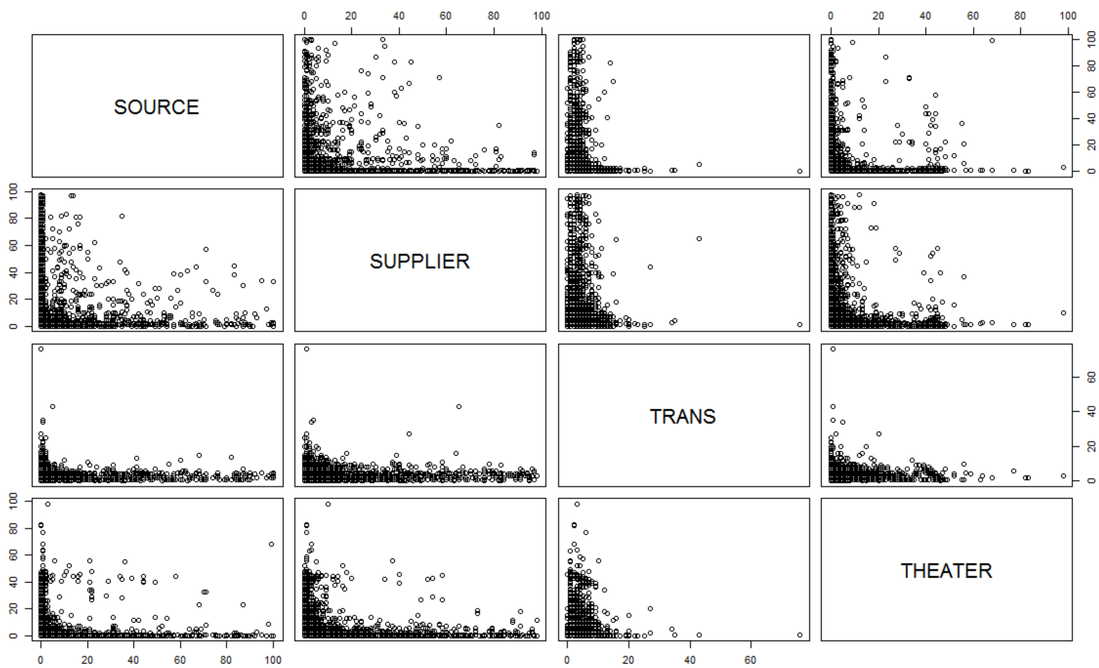

Figure 11. Paired Scatter Plots for the “Segment Days” Variables Excluding Outliers. No discernable pattern appears, supporting the independence assumption.

D. STATISTICAL ANALYSIS

The Issue Priority Group (IPG) defines the importance of a requisition. DOD logistic support business rules require that the fastest shipping lanes be assigned requisitions in IPG 1. Thus, requisitions in IPG 1 should move faster through the network than requisitions in IPG 2 or IPG 3. A boxplot of CONUS LRTs by IPG (Figure 12) shows that may not be true. The mean and median table (Table 5) supports the finding.

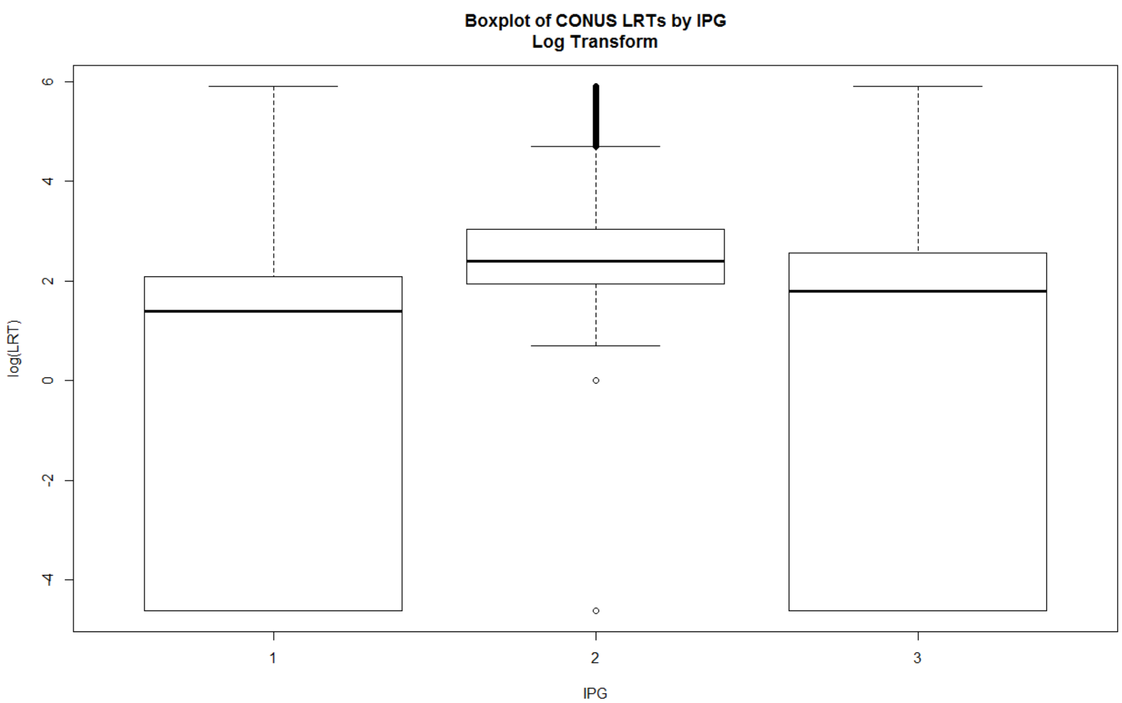

Figure 12. CONUS Logarithm Transformed LRT Boxplot. The boxplot appears to show that IPG 3 requisitions have a lower mean and median LRTs than IPG 2.

Table 5. CONUS LRT Summary Statistics

	IPG 1	IPG 2	IPG 3
LRT Mean	9.1	22.6	13.5
LRT Median	4.0	11.0	6.0
LRT Std Dev	22.9	36.6	29.2
Observations	4,060,707	789,845	4,012,861

We hypothesize the assigned IPG does not have an effect on the overall LRT. We apply hypothesis testing to the segments, leveraging the independence demonstrated in section C.

1. Friedman Test

We conducted non-parametric analysis on the “Segment Days” variable’s median value for each segment using the Friedman Test. We reject the null Hypothesis that median “Segment Days” are the same for all IPGs at a 0.05 level. The hypotheses are:

H_0: “The median days in a segment are equal for all IPGs.”

H_a: “The median days in a segment is different for at least one IPG.”

Using the Friedman Test results we reject the null hypothesis for the Supplier and Theater segments for both CONUS and OCONUS (see p-values on Table 6). Requisitions have different median speeds through the Supplier and Theater segments. We cannot reject the null hypothesis of equal median speed for the transporter segment (see p-values on Table 6).

Table 6. Friedman Test p-values

Segment	CONUS	OCONUS
Depot	0.0122	0.000674
Transporter	0.607	0.913
Theater	0.00456	0.000111

2. Nested F-Test

We further test the transporter segment's requisition speed by IPG using a nested F-Test. The nested F-Test determines if adding information to a model improves performance. We apply the test to each transporter segment element in both data sets.

For the OCONUS data set we reject the null hypothesis and state that adding IPG improves model performance for the "Ocean" method only. We cannot reject the null hypothesis for the other elements (see p-values on Table 7). Element "Small Packages Shipped Air" has only two observations, both IPG 1, so no test is possible for that method. We conclude no relationship between transport segment handling of IPGs and LRT exists with the exception of the "Ocean" method. A boxplot and histograms (Figure 13) of LRTs by IPG for the "Ocean" method suggest a longer total shipping time for requisitions assigned IPG 1 than requisitions shipped IPG 3. Defense Logistics Manual 4000.25-1 (2015) requires highest priority shipments be assigned IPG 1 and lowest priority assigned IPG 3; thus, IPG 1 shipments should have shorter total shipping times (AP2.14-7).

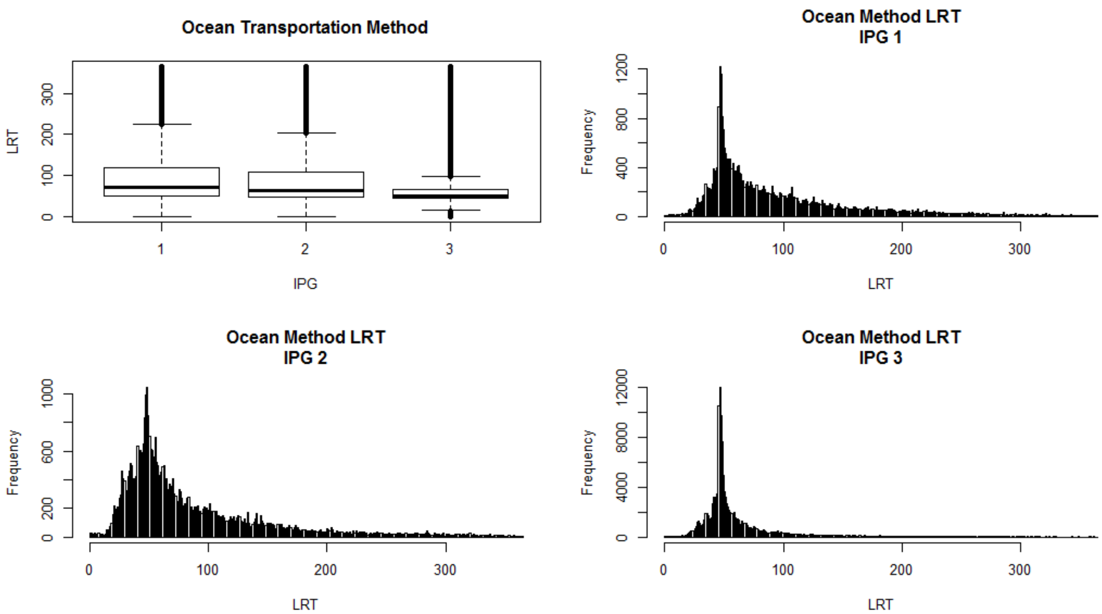

Figure 13. Ocean Transportation Method LRTs by IPG. The Plots Show a Smaller Variance and Lower Mean for IPG 3.

Table 7. OCONUS Transport Method Nested F-Test p-values. See Appendix E for Acronym List.

Trans Method	p-value
Comm Express	0.552
MILAIR	0.496
Ocean	0.007
MILALOC	0.057
CAT A	0.042
Other Truck	0.796
Local Truck	0.265
Scheduled Truck	0.039

For the CONUS data set we cannot reject the null hypothesis. There is no statistical evidence to support the conclusion that adding IPG improves model performance for any transportation method (see p-values in Table 8). We conclude that there is no relationship between transport segment handling of IPGs and LRT within the CONUS data set.

Table 8. CONUS Transportation Method Nested F-Test p-values

Trans Method	p-value
Grnd Local	0.510
Grnd Sm Pkg	0.098
Air Sm Pkg	0.461
Grnd Scheduled	0.462
Unknown	0.832
Other	0.058
Air Parcel Post	0.528
Grnd LTL	0.662

E. DISTRIBUTION NETWORK IMPROVEMENT ANALYSIS

The primary objective of the improvement analysis is to identify which stream elements to improve which make the greatest number of streams that fail to meet the TDD standard, or “poor” streams, into streams that do meet the TDD standard, “good” streams. USTRANSCOM defines a “good” stream as one whose 85^{th} LRT quantile is less than or equal to the stream’s TDD. Using USTRANSCOM’s standard, we classify 45 of the 510 CONUS streams (11%) and 347 of the 1906 OCONUS streams (18%) as “good.”

Using the segment independence established in section C we focus improvements on the individual segments. Implementing the improvement algorithm generates a matrix of improvements. This matrix represents the total number of streams defined as “good” by improving a segment element by a budgeted number of days (see Table 9 for sample output). Figure 14 shows line plots of the total number of improved streams by element and Figure 15 shows an expanded view. We use the improvement matrix to maximize number of improved streams across the network. For example, improving the “Segment Days” variable of all “DLA CONUS” requisitions by one day increases the number of “good” streams in the network from 13 to 15. We seek to allocate a fixed number of available improvement days across the elements in the network to produce the maximum increase in the number of “good” streams.

Table 9. Sample Improvement Algorithm Output. The rows represent the total number of "good" streams associated to an element as the element is improved. The columns represent the number of improvement days applied to an element.

Days	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
ELEMENT											
DLA CONUS	13	15	15	15	16	16	16	16	16	16	16
DLA DVD	1	1	1	1	1	1	2	2	2	2	2
DDSP	5	6	6	7	7	8	9	9	9	9	9
DDJC	11	11	12	12	12	12	12	12	12	12	12
Other	7	8	8	11	11	11	11	11	11	11	11
DLA NP DVD	6	7	7	7	7	7	7	7	7	7	7
Planned DVD	5	5	6	6	6	6	7	8	8	8	8
DDRT	8	10	10	10	10	10	11	11	11	11	11
GSA	1	1	1	1	1	1	1	1	1	1	1
Grnd Local	5	6	6	6	6	6	6	6	6	7	7
Grnd Sm Pkg	11	13	14	16	19	19	19	19	19	19	19
Air Sm Pkg	8	11	13	13	14	15	16	16	16	16	17
Grnd Scheduled	9	11	11	11	12	12	12	12	12	12	12
Unknown	10	10	10	10	10	10	10	10	10	10	10
Other	7	8	10	11	11	11	11	11	11	11	11
Air Parcel Post	1	1	1	1	1	1	1	1	1	1	1
Grnd LTL	4	4	4	4	6	7	7	7	8	8	8
Comm Express	0	0	0	0	0	0	0	0	0	0	0
Central	15	16	16	16	19	19	22	22	22	22	22
West	18	20	22	23	23	24	28	29	30	30	31
Southeast	14	17	19	20	24	25	26	28	28	29	29
Northeast	7	8	8	9	10	10	14	14	14	14	14
US Other	1	1	1	1	1	1	3	4	4	4	4

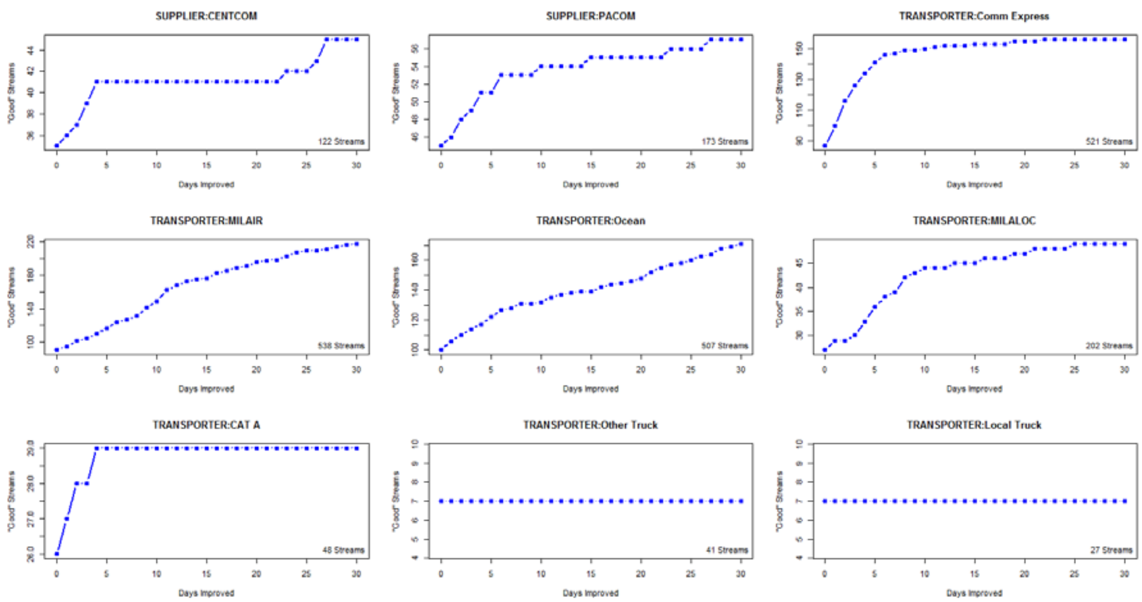

Figure 14. Improvement Algorithm Lower Bound Sample Output. The x-axis shows the total days of improvement for the element; the y-axis shows the total number of "good" streams associated with the element; the text to the bottom right shows the total number of associated streams.

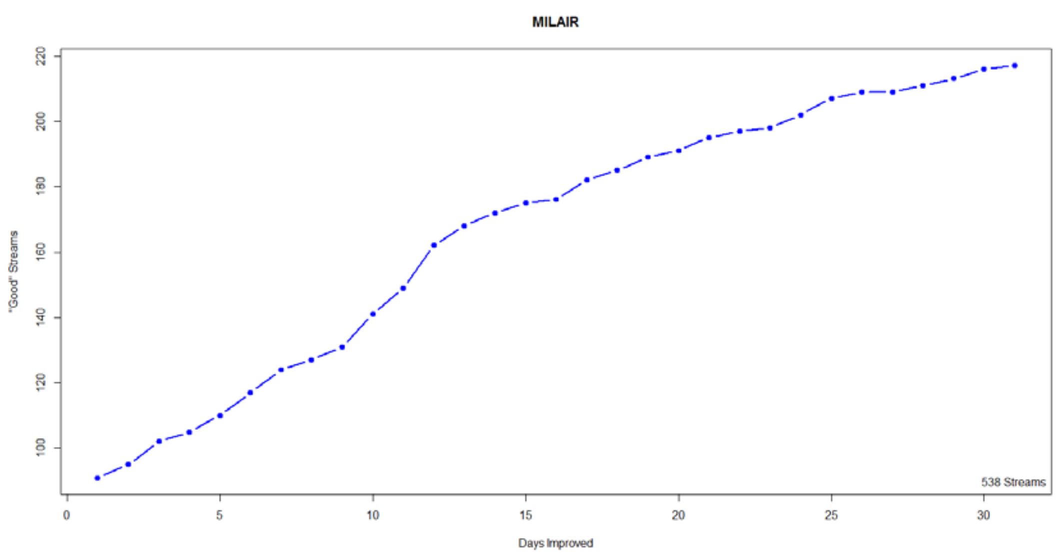

Figure 15. Decision Maker Plot for the MILAIR Element. Initially, MILAIR is associated with 91 "good" streams. That number increases to 95 by improving all available requisitions by one day. The plot also shows that improvements are not linear and that the increase appears to taper off as the improvement increases.

The optimization results in a lower bound. The high number of missing values in the “Segment Days” variables limit the total number of LRTs adjusted within the algorithm. This artificially inflates the 85th quantile after each iteration (see Chapter III, section C, paragraph 3 for a full description of the algorithm). Using the budget of 20 improvement days improves at least 149 OCONUS streams and at least 40 CONUS streams (see Table 10 and Appendix D for improvement strategies).

To get an upper bound we replace a requisition’s missing values with the maximum time allowed by SDDB business rules, 365 days, and run the improvement algorithm again. Using the budget of 20 improvement days for both the CONUS and OCONUS networks improves at most 187 OCONUS streams and 59 CONUS streams (see Table 11 and Appendix D for improvement strategies).

The strategies shown in Tables 10 and 11 provide the allocation that maximizes the total increase in “good” streams given a 20 day improvement budget for the OCONUS network. No segment appears more important than the others. However, OCONUS military air shipments appear to provide the greatest return on investment for the lower bound and commercial air shipments the greatest return for the upper bound.

Table 10. OCONUS Improvement Strategy; Lower Bound. See Appendix E for Acronym List.

Element	**Segment**	**Days Element Improved**	**Improved Streams**
EUCOM	Depot	1	6
DDJC	Depot	1	6
Ocean	Trans	1	6
Comm Express	Trans	5	54
MILAIR	Trans	12	77
	TOTAL	**20**	**149**

Table 11. OCONUS Improvement Strategy; Upper Bound. See Appendix E for Acronym List.

Element	**Segment**	**Days Element Improved**	**Improved Streams**
DDJC	Depot	1	7
EUCOM	Depot	2	13
MILAIR	Trans	2	15
Comm Express	Trans	15	152
	TOTAL	**20**	**187**

The elements in the strategies differ for the upper and lower bounds with the upper bound containing a subset of the lower bound elements for this example. Additional runs using the same data with varying improvement days budgets produce strategies with different elements in each. The combination of plots and optimized strategies helps the decision maker better understand the effects of improvement across the network, enabling better recommendations.

IV. CONCLUSIONS AND FUTURE WORK

Data quality was the most significant limitation to the research, and it also limits USTRANSCOM's ability to manage and improve the distribution network. The large number of incomplete cases within the "Segment Days" variables makes an accurate estimate of the number of streams that can be improved impossible. The high proportion of missing "Segment Days" values casts doubt on the validity of the statistical tests, particularly for the CONUS network where the Theater and Transporter segments are missing over half of the values. We recommend that the Department of Defense take steps to improve the data quality to enable better network assessment, either by requiring digital logistic tools used by major global shipping companies or by scrapping the SDDB and creating a new system.

The missing values also affected the improvement algorithm by not allowing us to build a complete process diagram for each requisition. Without a complete diagram for a requisition the improvement available cannot be known, only bounded. Under this technique every process with a missing value was assumed to have zero days of improvement available for the lower bound and infinite improvement days available for the upper bound. More complete "Segment Days" distributions would allow the algorithm to accurately calculate the number of streams improved using a given strategy. A decision maker would make better use of a pinpoint estimate than a bound when allocating funds to execute improvements. However, the bounded results still provide useful information.

The segments within DOD requisition distribution pipeline are independent. An improvement of a number of days to any segment within a stream improves the entire stream by the same number of days. Thus, an improvement in one element of a segment improves all connected streams; that is, all requisitions using that segment decrease their LRT by 1 day. USTRANSCOM should focus network improvement strategies on the separate stream elements. USTRANSCOM should also treat the CONUS and OCONUS networks as distinct from one another and create improvement strategies for both.

Elements within Supplier and Theater Segments appear to treat requisitions differently based on Issue Priority Group. The Transportation Segment does not. Only the Ocean element within the Transporter Segment showed a statistically significant difference in the treatment of requisitions based on IPG for both the CONUS and OCONUS networks. Boxplots of the Ocean element suggest faster movement through the segment for IPG 3 requisitions than IPG 1 or IPG 2.

While analysis using the current stream variables identifies general network issues, it cannot identify specific capability gaps. Future work in this area should include an in-depth study of the sub-elements within the segment variables (e.g., physical depots, transportation contractors, or requisitioning units) to identify specific improvement recommendations. Additionally, the SDDB contains “days-in-process” information on the distribution sub-processes within each segment. An analysis including this information would provide greater fidelity and inform more useful improvement strategies.

APPENDIX A. LIST OF STREAM VARIABLES

A list of all elements contained within the Stream Information variables.

We divide the table by segment.

Table 12. List of Variables by Segment; CONUS and OCONUS Combined

SUPPLIER		
DLA CONUS	Other	GSA
DLA DVD	DLA NP DVD	EUCOM
DDSP	Planned DVD	CENTCOM
DDJC	DDRT	PACOM
TRANSPORTER		
Grnd Local	Air Parcel Post	MILALOC
Grnd Sm Pkg	Grnd LTL	CAT A
Air Sm Pkg	Comm Express	Other Truck
Grnd Scheduled	MILAIR	Local Truck
Unknown	Ocean	Scheduled Truck
Other		
THEATER		
Central	Germany	Puerto Rico
West	Spain	Virgin Islands
Southeast	Turkey	Mexico
Northeast	S. Italy	Okinawa
United States Other	N. Italy	Japan
Djibouti	Cyprus	Korea (South)
Niger	Azores	Diego Garcia
Ethiopia	Luxembourg	Hawaii
Seychelles	Belgium	Guam
Kuwait	Greenland	Northern Mariana Islands
Oman	North Atlantic	Australia
Qatar	Balkans	Singapore
United Arab Emirates	Romania	Philippines
Afghanistan	Bulgaria	Hong Kong
Jordan	Greece	Cuba
Saudi Arabia	Israel	Honduras
Iraq	Austria	Colombia
Bahrain	Iceland	Panama
United Kingdom	Alaska	
ADDITIVE		
None	Medical	Afloat,GSch JC
ASmPkg SP	Afloat,ASmPkg SP	SoIt Local
ASmPkg JC	Afloat	Sp Truck
GSch SP	Afloat,ASmPkg JC	AF 3PL
GSch JC	Afloat,GSch SP	Afloat,Sp Truck

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APPENDIX B. SUMMARY STATISTICS

A list of summary statistics for the “Segment Days” variables.

Table 13. Summary Statistics of the “Segment Days” Variables by Element for CONUS and OCONUS Combined.

ELEMENT	MINIMUM	MEDIAN	MEAN	MAXIMUM	SD	MISSING
DAYS_DOC_D6_NO_BKORDR (LRT)						
All Requisitions	0.00	6.00	14.42	365.00	29.82	0.00
DAYS_SOURCE_NO_BKORDR (SOURCE SEGMENT)						
All Requisitions	0.00	1.00	3.25	365.00	16.09	251602.00
DAYS_SUPPLIER (SUPPLIER SEGMENT)						
CENTCOM	0.00	1.00	2.66	146.00	6.56	204.00
DDJC	0.00	1.00	2.00	337.00	4.70	1969.00
DDRT	0.00	1.00	1.54	359.00	2.97	400.00
DDSP	0.00	1.00	3.18	354.00	9.73	14659.00
DLA CONUS	0.00	0.00	1.46	361.00	5.88	34169.00
DLA DVD	0.00	7.00	21.47	357.00	34.73	18555.00
DLA NP DVD	0.00	2.00	4.23	352.00	7.80	6389.00
EUCOM	0.00	1.00	3.25	255.00	4.98	529.00
GSA	0.00	14.00	31.25	348.00	42.32	27493.00
Other	0.00	2.00	6.63	365.00	21.12	1347076.00
PACOM	0.00	1.00	2.23	235.00	5.79	85668.00
Planned DVD	0.00	4.00	11.24	362.00	23.72	28446.00
DAYS_TRANSPORTER (TRANSPORTER SEGMENT)						
Air Parcel Post	0.00	2.00	3.06	360.00	4.57	304851.00
Air Sm Pkg	0.00	2.00	2.17	302.00	1.75	118118.00
CAT A	0.00	9.00	8.20	39.00	2.63	7914.00
Comm Express	0.00	4.00	4.30	307.00	4.57	69091.00
Grnd Local	0.00	4.00	7.54	130.00	13.74	1433428.00
Grnd LTL	0.00	5.00	5.53	210.00	4.27	122451.00
Grnd Scheduled	0.00	2.00	2.21	300.00	1.62	45584.00
Grnd Sm Pkg	0.00	5.00	5.25	308.00	3.39	521126.00
Local Truck	0.00	0.00	0.00	0.00	0.00	207.00
MILAIR	0.00	9.00	10.78	302.00	9.27	14850.00
MILALOC	0.00	6.00	6.59	134.00	3.68	3917.00
Ocean	0.00	28.00	28.49	302.00	16.45	19433.00
Other	0.00	3.00	3.63	143.00	4.47	218181.00
Other Truck	0.00	0.00	0.00	0.00	0.00	85183.00
Scheduled Truck	0.00	0.00	0.00	0.00	0.00	351.00
Unknown	0.00	2.00	2.89	355.00	7.94	1264344.00

ELEMENT	MINIMUM	MEDIAN	MEAN	MAXIMUM	SD	MISSING
DAYS_THEATER (THEATER SEGMENT)						
Afghanistan	0.00	1.00	3.39	313.00	9.08	6653.00
Alaska	0.00	3.00	5.82	339.00	9.37	12801.00
Australia	0.00	7.00	14.80	339.00	26.12	503.00
Austria	1.00	1.00	14.50	42.00	20.92	0.00
Azores	0.00	12.00	16.77	145.00	18.10	285.00
Bahrain	0.00	5.00	12.13	347.00	24.48	8296.00
Balkans	0.00	6.00	6.90	292.00	7.47	157.00
Belgium	0.00	17.00	17.14	34.00	11.99	0.00
Bulgaria	3.00	25.00	34.93	134.00	27.50	0.00
Central	0.00	1.00	3.63	357.00	8.26	1319996.00
Colombia	0.00	44.50	37.75	62.00	26.51	0.00
Cuba	0.00	3.00	24.92	265.00	42.13	40.00
Cyprus	0.00	1.00	6.58	239.00	17.37	303.00
Diego Garcia	0.00	8.00	19.80	313.00	33.61	278.00
Djibouti	0.00	1.00	6.80	288.00	19.57	2600.00
Ethiopia	0.00	3.00	26.02	280.00	55.08	27.00
Germany	0.00	3.00	5.79	352.00	11.22	5605.00
Greece	0.00	5.00	20.38	348.00	42.46	55.00
Greenland	0.00	16.00	18.84	70.00	17.60	21.00
Guam	0.00	12.00	22.56	349.00	30.48	3187.00
Hawaii	0.00	4.00	8.85	364.00	17.77	100341.00
Honduras	0.00	1.00	4.90	281.00	20.75	126.00
Hong Kong	1.00	13.00	15.11	45.00	10.24	7.00
Iceland	NA	NA	NA	NA	NA	17.00
Iraq	0.00	30.00	29.99	131.00	14.20	423.00
Israel	4.00	10.00	16.14	50.00	14.96	6.00
Japan	0.00	4.00	9.32	361.00	19.58	23501.00
Jordan	0.00	10.00	13.91	233.00	15.52	950.00
Korea (South)	0.00	2.00	4.00	349.00	10.43	6597.00
Kuwait	0.00	3.00	5.49	342.00	10.15	11642.00
Luxembourg	0.00	20.00	19.61	104.00	16.77	27.00
Mexico	12.00	12.00	12.00	12.00	NA	1.00
N. Italy	0.00	8.00	11.16	340.00	13.06	1599.00
Niger	0.00	1.00	5.41	47.00	10.73	233.00
North Atlantic	0.00	18.00	43.84	286.00	56.15	265.00
Northeast	0.00	1.00	5.54	356.00	15.40	381722.00
Northern Mariana Islands	3.00	16.50	14.89	31.00	8.24	54.00
Okinawa	0.00	2.00	6.54	362.00	17.69	13161.00
Oman	0.00	3.00	8.37	174.00	14.21	968.00
Panama	2.00	5.00	4.33	7.00	1.97	3.00
Philippines	0.00	15.00	19.08	329.00	23.16	61.00
Puerto Rico	0.00	12.00	15.15	315.00	19.16	1480.00
Qatar	0.00	1.00	5.50	350.00	16.73	5404.00
Romania	0.00	11.00	25.32	328.00	41.91	103.00
S. Italy	0.00	4.00	12.41	351.00	29.40	2126.00
Saudi Arabia	0.00	3.00	5.48	34.00	7.55	4.00
Seychelles	NA	NA	NA	NA	NA	164.00
Singapore	0.00	24.00	33.95	356.00	40.44	1250.00
Southeast	0.00	1.00	4.18	362.00	13.39	1071481.00
Spain	0.00	7.00	14.59	358.00	27.73	1522.00
Turkey	0.00	11.00	11.71	275.00	12.86	1565.00
UAE	0.00	1.00	14.73	360.00	35.75	12658.00
United Kingdom	0.00	3.00	5.50	329.00	9.83	5545.00
US Other	0.00	16.00	22.65	362.00	23.64	166846.00
Virgin Islands	1.00	1.00	1.00	1.00	NA	2.00
West	0.00	1.00	3.41	362.00	11.53	1091791.00

APPENDIX C. LOGISTIC RESPONSE TIME BOXPLOT

LRT boxplots for the CONUS and OCONUS data sets. These boxplots highlight the high variance in the LRTs.

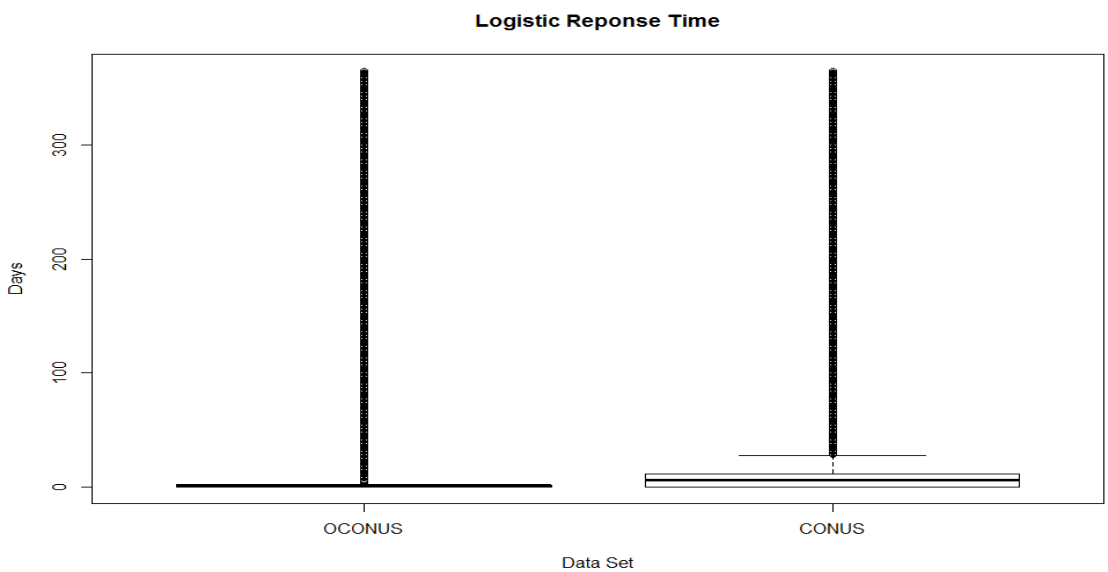

Figure 16. Logistic Response Time for Each Complete Data Set; y-axis Not Transformed.

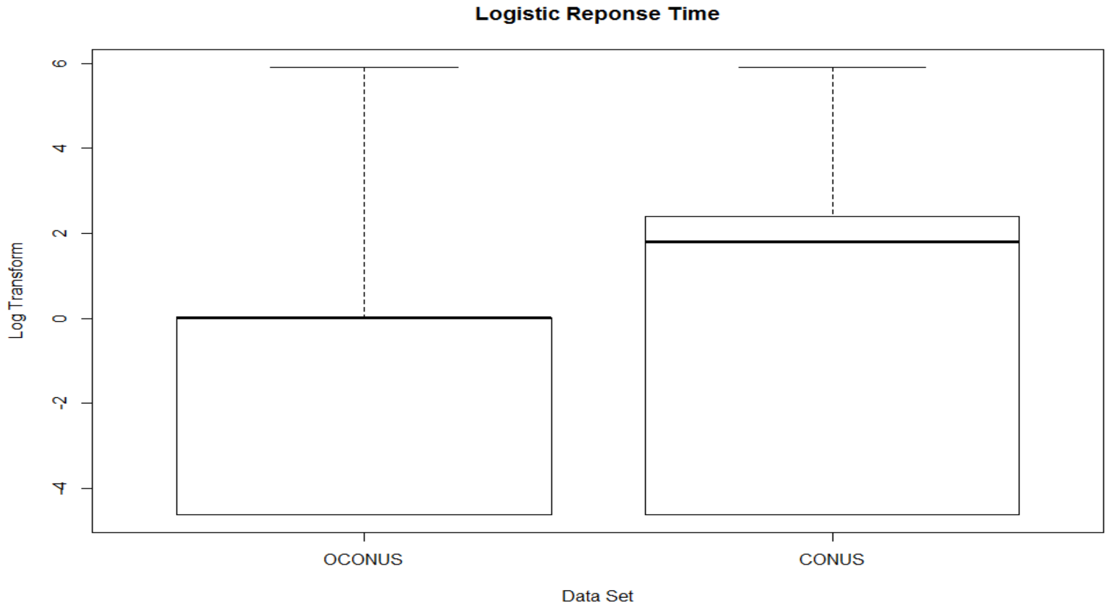

Figure 17. Logistic Response Time for Each Complete Data Set; y-axis log-transformed.

APPENDIX D. STREAM IMPROVEMENT PLOTS

A set of decision-maker plots with a 30 day improvement budget. The plots allow non-technical decision makers to better understand how improvements affect the overall network.

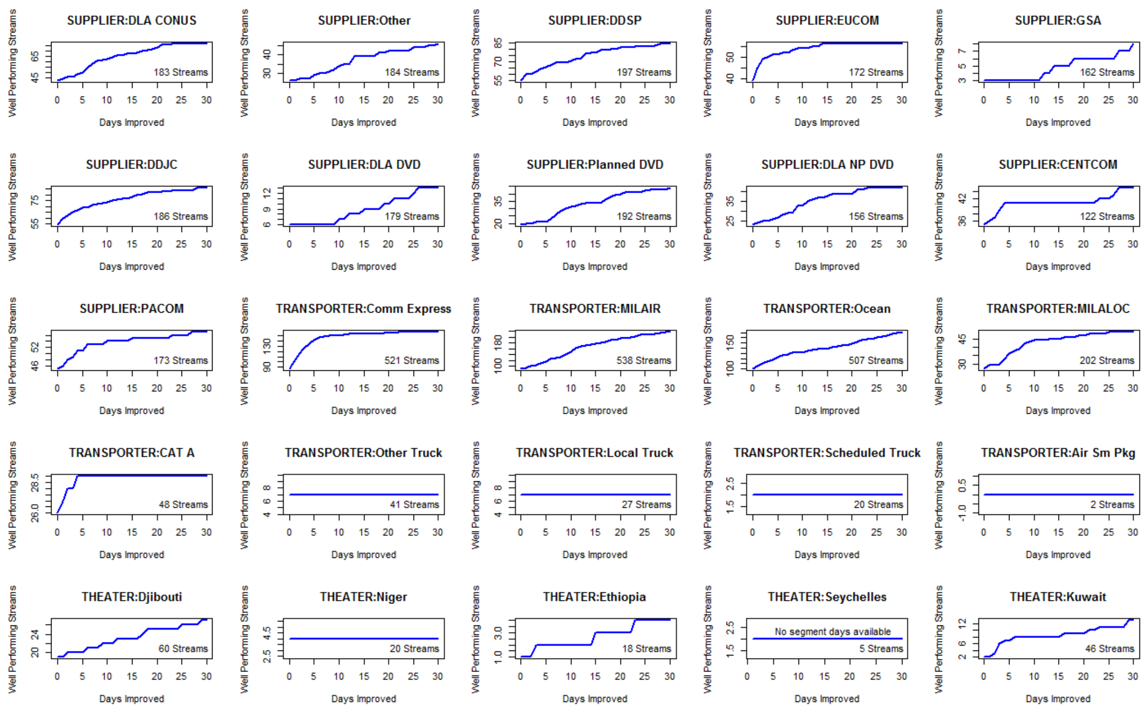

Figure 18. OCONUS Stream Improvement Decision Maker Plots; 1 of 3.

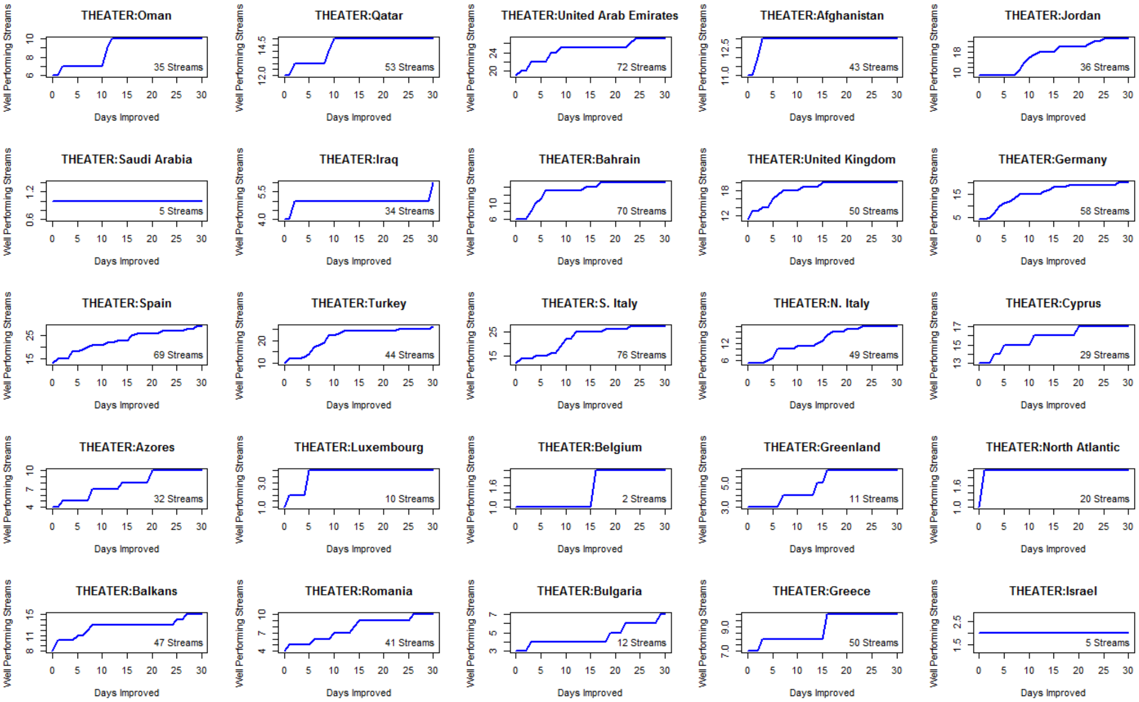

Figure 19. OCONUS Stream Improvement Decision Maker Plots; 2 of 3.

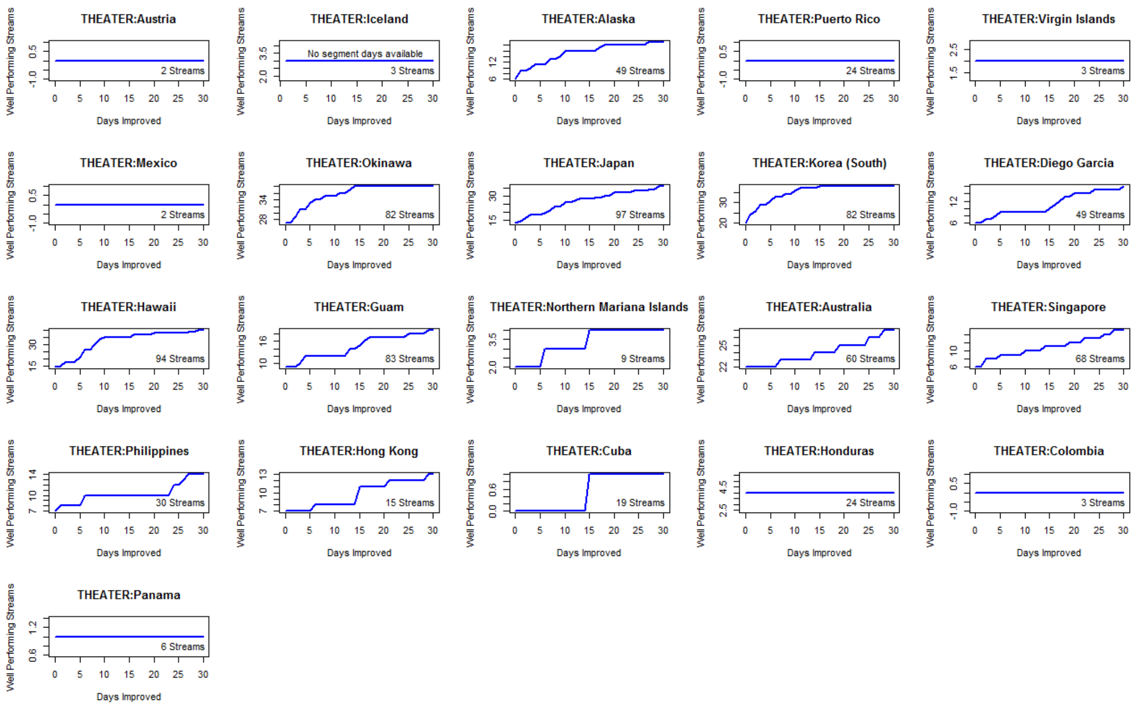

Figure 20. OCONUS Stream Improvement Decision Maker Plots; 3 of 3.

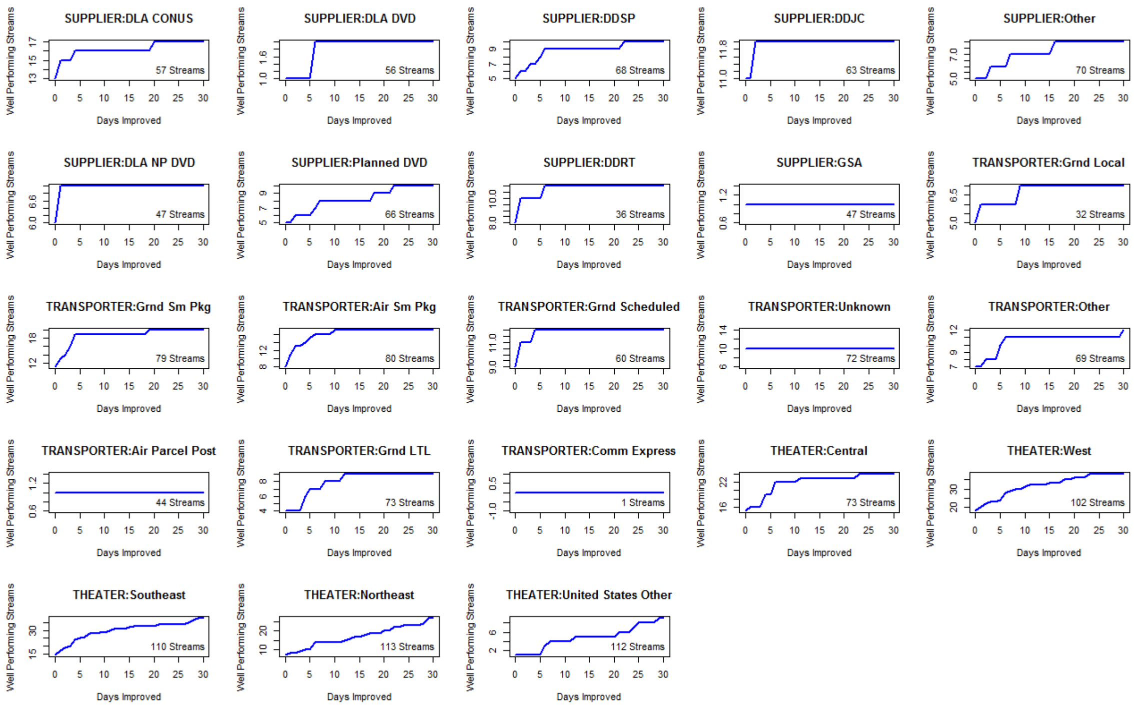

Figure 21. CONUS Stream Improvement Decision Maker Plots.

Table 14. CONUS Improvement Strategy; Upper Bound.

Element	Segment	Days Element Improved	Improved Streams
DLA CONUS	Depot	1	2
West	Theater	1	4
DDRT	Depot	2	6
Air Sm Pkg	Trans	3	10
Southeast	Depot	4	12
Other	Theater	9	25
	TOTAL	**20**	**59**

Table 15. CONUS Improvement Strategy; Lower Bound.

Element	**Segment**	**Days Element Improved**	**Improved Streams**
DLA CONUS	Depot	1	2
DDRT	Depot	1	2
Grnd Scheduled	Trans	1	2
Air Sm Pkg	Trans	2	5
Other	Depot	2	3
West	Theater	2	4
Grnd Sm Pkg	Trans	4	8
Southeast	Theater	7	14
	TOTAL	**20**	**40**

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APPENDIX E. VARIABLE ACRONYM LIST

Table 16. List of Variable Acronyms.

SUPPLIER	
DLA CONUS	DLA Managed depots within CONUS
DLA DVD	DLA managed planned direct vendor deliveries
DDSP	Defense Depot Susquehanna, Pennsylvania
DDJC	Defense Depot San Joaquin, California
Other	Miscellaneous supply sources not covered by other variables
DLA NP DVD	DLA managed unplanned direct vendor deliveries
Planned DVD	Planned direct vendor deliveries not managed by DLA
DDRT	Defense Depot Texarkana, Texas
GSA	General Services Administration
EUCOM	Supply sources within Europe Command
CENTCOM	Supply sources within Central Command
PACOM	Supply sources within Pacific Command
TRANSPORTER	
Grnd Local	Local truck
Grnd Sm Pkg	Ground small packages
Air Sm Pkg	Air small packages
Grnd Scheduled	Ground scheduled
Grnd LTL	Ground less than truckload
Comm Express	Commercial express
MILAIR	Military air, pallets built by aerial port
MILALOC	Military Air, pallets built by supplier
CAT A	Category A movement

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